*Taung Phamong Rural Development Project, Lesotho*

# *Groundwater Project*

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Prepared For:
**Saskatchewan Agricultural Development Corporation**

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## Groundwater Project

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# SUMMARY

Prior to 1988 little emphasis was placed on systematic collection of the hydrogeological data necessary to better understand the groundwater resources in the Taung Phamong Rural Development Project area. Consequently, in 1988 a program was set up aimed at obtaining more specific hydrogeological data. This program includes: systematic documentation of borehole data using forms specifically developed for this purpose, the establishment of a groundwater level monitoring network and systematic collection of water quality data. The groundwater monitoring network consists of six observation wells equipped with continuous recorders and eleven sites where the water level is measured once per month. The objective of the network is to obtain information on the nature and magnitude of water level fluctuations, in relation to precipitation and groundwater withdrawals. The water quality program consists of collection of water samples from selected boreholes for detailed chemical analysis and of collecting selected water quality data from boreholes drilled after 1987.

Personnel of Village Water Supply will be responsible for the collection and processing of the field data and has been trained in operating the water level recorders and instruments used for collection of water quality data. Local office staff has been trained in using computer programs for processing of the field data.

This report provides an initial description the hydrogeological setting of the Taung Phamong Rural Development Project area. It also documents the groundwater level monitoring network which was set up.

Initial records from the observation wells are discussed as are the water quality data which were collected.

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# 1. INTRODUCTION

The groundwater study component of the Taung Phamong Rural Development Project, Mohale's Hoek District, Lesotho, has the following objectives:

1. Establish and describe the hydrogeological setting of the Taung Phamong Rural Development Project area.
2. Establish a groundwater monitoring network to investigate the impact of groundwater use on water levels and to obtain a qualitative insight into the nature and magnitude of recharge.
3. As an aid to objectives 1 and 2:
   - 3a. Develop a program for collecting and recording of basic geological and hydrogeological data from boreholes.
   - 3b. Develop a computer data base for storage and retrieval of past and future borehole data.
   - 3c. Develop a program of collecting basic water quality data (pH, temperature and conductivity) from existing boreholes.
   - 3d. Develop a program for documenting and analyzing bail test data.

The present report combines the results from an orientation visit made to the Taung Phamong Rural Development Project from January 15 to January 29, 1988, and a second visit made from September 22 to October 9, 1988.

During the orientation visit relevant geological and hydrogeological data were collected as well as meteorological data. Sites for construction of observation wells were selected and water was obtained from selected boreholes for chemical analysis. The initial results from this visit were documented by Maathuis (1988a). As a result of this visit a Borehole Data Summary form and a form for Bail Test Data and Analysis were developed for use in the drilling program (see Appendix A).

During the second visit water level recorders and rain gauges were installed and water level data were collected. Personnel of Village Water Supply, Mohale's Hoek, as well as project staff were trained in the use of the equipment. Computer programs for processing data to be collected were set up on the personal computer in the project office and personnel was trained in the use of the programs.

# 2. BACKGROUND INFORMATION

In the period 1983 to 1987, 450 to 475 boreholes were drilled in the project area (see Map No.1 in back of this report) for village water supply purposes. About 70% of these boreholes yielded a sufficient amount of water for installation of a hand pump. A total of 320 hand pumps were installed in 125 villages. In several cases a borehole yielded sufficient water (0.1 L/s) for installation of a positive displacement pump powered by a diesel engine.

In one case, the Village of Siloe, the pump is driven by an electrical motor. Since 1987, the Village of Ha Thaba Bosiu uses water obtained from a borehole equipped with a pump powered by electricity generated by solar panels.

In 1988, to the end of September, about 103 boreholes were drilled of which 62 yield enough water for installation of a hand pump.

Borehole siting and drilling of the borehole is the responsibility of the Taung Phamong Rural Development Project. Supply of hand pumps and hand pump installation has been the responsibility of Village Water Supply (VWS), Ministry of Interior, Chieftainship Affairs and Rural Development, Government of Lesotho. Initially, Moyno handpumps were installed but later VWS installed Mono pumps. The purchase of hand pumps is funded by USAID and the Government of Lesotho. For the remainder of the program hand pumps will be supplied by the Taung Phamong Rural Development Project.

**Figure 1. Cable tool equipment used for bail tests and development of boreholes.**

Contribution of the villagers toward the borehole drilling program is in the form of a payment of 20 Maloti per family, collection of crushed stones and sand for the cement slab for the pump, and providing accommodation and sustenance for workers.

Borehole siting is done by visiting villages and looking for ob-

vious indications of the presence of dikes and by using vegetation, springs and termite hills as indicators of the presence of water. A set of aerial photos (scale 1:20,000) for the study area is being used since September 1988 to aid in the siting process.

Depending on the geological setting, typically an attempt was made to locate a borehole within a distance of about 300 metres from the houses. Each well site provides water to about 20 to 25 families, or 75 to 100 persons. It is estimated that the usage may range from 7 to 9 litres per day per person. Village Water Supply uses a value of 30 litres per capita per day in designing water supply systems.

The location of the borehole site was often determined by "witching or dowsing", done by either the Project Manager or the driller. In the initial stages of the borehole drilling program a magnetometer was used sporadically in determining the borehole location. However, compared to the witching method, the use of a magnetometer was found to be time consuming and less efficient. Magnetometer measurements were also affected by the presence of metals.

Boreholes are drilled using a down-hole hammer and air-rotary equipment (Figure 2). Typically, the weathered zone is drilled with a 20 cm diameter bit, and 4 or 8 metres of 165 mm OD steel surface casing is installed. The remainder of the hole is drilled to a diameter of about 165 mm. The average depth of the boreholes drilled is about 68 metres.

The bottom of a hand pump is typically set at about 6 to 10 metres above the bottom of the hole.

At the beginning of the borehole drilling program an attempt was made to document the lithology encountered in the boreholes. However, since it was discovered that the lithology and changes in the lithology were poorly recorded this practice was abandoned. Consequently, for the boreholes drilled prior to 1988 lithological information is available only for a limited number of holes. A systematic procedure for collecting lithological information was set up for the 1988 drilling program. This procedure consists of documenting the lithology based on samples collected for every metre drilled.

**Figure 2. Air-rotary drilling rig and compressor used in drilling program.**

Generally, a static water level is available for the boreholes, measured either at the time a bail test was carried out or prior to installation of the hand pump. However, information on the depth at which water was struck is generally not recorded for the boreholes drilled prior to 1988. Typically, water rises to about 20 to 25 metres above the depth at which water was struck initially.

Depending on the anticipated yield of a borehole, the yield was determined by either blowing water out of the hole using the air-lift method or by conducting a bail test. When using the air-lift method, water was ponded at the surface and a pipe was used to determine the discharge rate. The amount of discharge, in litres per hour, was recorded. In bail tests, a cable tool rig (Figure 1) and a 30 litre bailer is used to evacuate water from the borehole. After 10 bailer volumes were removed from the hole, the depth to water was measured and was recorded together with the time of measurement. This process was repeated several times until a large drawdown was created in the well. Subsequently, the water level recovery was measured and recorded. The rate of recovery varies but in most cases complete recovery occurred within 24 hours. Based on the rate of inflow, the borehole was rated as having a "recharge" ranging from marginal to very good. If the recovery rate was less than 3 m/hr, the borehole was considered as unsuitable for hand pump installation. Recovery within a period of a couple of hours was classified as very good "recharge".

For each village where hand pumps were installed the following documentation exits: a copy of a 1:20,000 topographical map with the approximate location of the hand pumps and hand pump number, static water level, air-lift pumping rate or bail test data. These data are filed with Village Water Supply in Mohale's Hoek and Maseru. Copies are available in the office of the Taung Phamong Rural Development Project.

# 3. CLIMATE

The Mohale's Hoek weather station is one of 15 weather stations in Lesotho. Although meteorological parameters such as precipitation, temperatures and relative humidity are measured on a daily basis, the Ministry of Works and Communication (197-.) has only published a complete listing of monthly rainfall data from 1896 to 1970. Augmented with monthly rainfall data for the period 1970 - 1987, obtained from the Hydrological Survey Department, available monthly and annual rainfall data for Mohale's Hoek are presented in Appendix B. It should be noted that the annual precipitation data are valid only for Mohale's Hoek and not for the entire study area since the amount of annual precipitation is a function of elevation. Bonney (1975e, Figure 2) suggests that in the study area there might be an increase in annual precipitation with increasing elevation. Lyon (1983) presented mean monthly temperatures and relative humidity data for 1977 - 1981. These data are presented in Table 1, together with the long-term mean monthly rainfall data. This Table shows that the hottest and wettest, and coldest and driest seasons coincide. The wet season occurs from October to April, and the dry season from May to September.

The long-term mean annual precipitation for Mohale's Hoek is 715 mm, based on 87 years of record. The annual deviation from this long-term mean annual precipitation is shown in Figure 3. This Figure shows periods of "wet" and "dry" years. It has been suggested that the precipitation records in the Republic of South Africa and in Lesotho follow a pattern of regularly spaced wet and dry spells each of 9 to 10 years in length (Eckert, 1980 and references therein).

**Table 1**
**Selected climatological data for Mohale's Hoek, Lesotho.**

| Month | Mean Temp.[1] (C) | Mean Relative Humidity[2] (%) | Mean Precip.[3] (mm) |
|---|---|---|---|
| January | 21.4 | 55.3 | 107.6 |
| February | 20.9 | 69.3 | 104.6 |
| March | 18.4 | 67.8 | 103.1 |
| April | 15.3 | 58.3 | 59.0 |
| May | 11.5 | 70.6 | 34.1 |
| June | 7.9 | 58.0 | 15.7 |
| July | 9.2 | 54.1 | 13.8 |
| August | 11.0 | 47.8 | 19.5 |
| September | 14.8 | 54.5 | 30.9 |
| October | 16.2 | 43.1 | 63.4 |
| November | 19.0 | 47.6 | 79.0 |
| December | 21.0 | 50.6 | 95.5 |

NOTES:
1) Mean monthly temperature data for 1977 - 1981 (Lyon, 1983)
2) Mean monthly relative humidity data for 1977 - 1981 (Lyon, 1983)
3) Long-term mean monthly precipitation (see Appendix B)

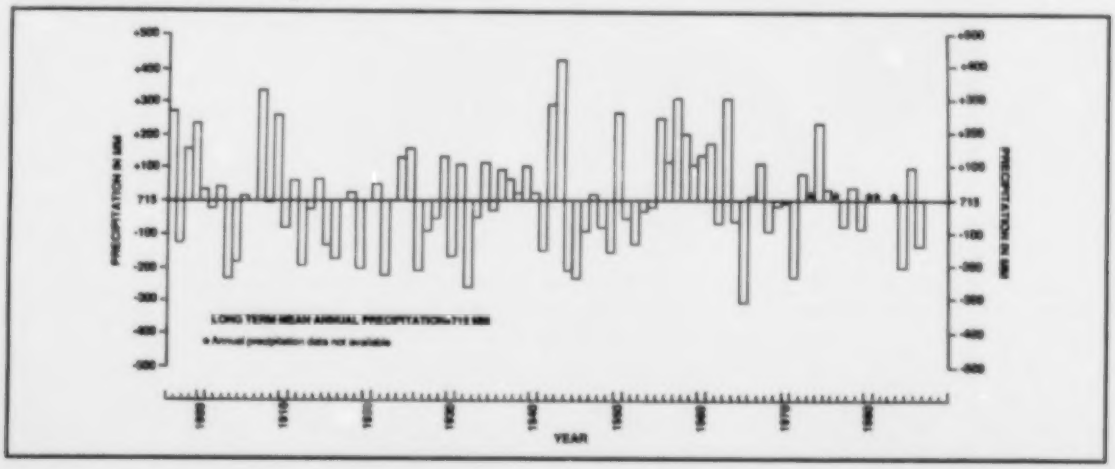


**Figure 3. Annual deviation from long-term mean annual precipitation, Mohale's Hoek, Lesotho**

# 4. GEOLOGY

Schmitz and Rooyani (1987) provide a summary of the geological history of Lesotho. The geological units exposed in Lesotho and those present below the surface belong to the sedimentary Karoo Basin.

Relevant to the project area are the following stratigraphical units, in ascending order: the Beaufort Group, the Stormberg Group, and the Drakensberg Group. The Beaufort Group and the Stormberg Group have been further subdivided into Formations. The stratigraphy and lithological characteristics of the stratigraphical units is shown in Figure 4. The following description of the stratigraphical units is mainly derived from the geological maps available for the project area.

## 4.1 Beaufort Group - Burgerdorp Formation

The Burgersdorp Formation is the upper unit in the Beaufort Group.

| STRATIGRAPHY | | | LITHOLOGY | Thickness (m) |
|---|---|---|---|---|
| KAROO SYSTEM | DRAKENSBERG GROUP | LESOTHO FORMATION | Basalt<br>Basalt with intercalations of sedimentary and volcanic origin | up to 900 |
| | STORMBERG GROUP | CLARENS FORMATION | "Cave sandstone":<br>Sandstone,fine-grained,creamy white, massive sandstones and siltstones | 1-200 |
| | | | "Transition zone": Siltstones, green,red very fine-grained, sandstones | 30-120 |
| | | ELLIOT FORMATION | Mudstones, siltstones, shaly, light green, purple and red;<br>fine and medium-grained sandstones,green, brown | 100-300 |
| | | MOLTENO FORMATION | Sandstones, coarse-grained gritty, buff,white colored;<br>finer-grained sandstones,green,light brown; buff , purple mudstones,siltstones; secondary silicification of sandstones | 100-200 |
| | BEAUFORT GROUP | BURGERSDORP FORMATION | Sandstones,fineand medium-grained,light green, buff colored;poly-colored silstones, mudstones | 60-120 |
| | | | | |

**Figure 4. Schematic stratigraphical and lithological setting of Taung Phamong Project Area.**

It is exposed in the northwestern part of the study area but underlies the whole area. The Burgersdorp Formation consists of light green and buff coloured, fine and medium-grained sandstones alternating with poly-coloured siltstones, mudstones and shales. Its exposed thickness may vary from 60 to 120 metres.

## 4.2 Stormberg Group

The Stormberg group has been subdivided into the following Formations, in ascending order: the Molteno Formation, the Elliot Formation and the Clarens Formation.

### 4.2.1 Molteno Formation

The Molteno Formation is the lowest unit of the Stormberg Group. The Formation consists of coarse-grained, gritty, arkosic, buff and white coloured bench-forming sandstones, alternating with finer grained green and light brown sandstones and green, buff and purple mudstones and siltstones. The sandstones have undergone a high degree of secondary silicification. The contact between the Molteno Formation and the underlying Burgersdorp Formation generally is sharp. The exposed thickness of the Molteno Formation in the project area may range from 100 to 200 metres.

### 4.2.2 Elliot Formation

The Elliot Formation, formerly known as "Red Beds", is the middle unit of the Stormberg Group. The Elliot Formation consists of light green, purple and red shaley mudstones and siltstones with bench-forming fine and medium-grained green and brown sandstones. In particular, in the upper part of the Elliot sequence, the mudstones, siltstones and sandstones might be brilliant red. The contact between the Elliot Formation and the underlying Molteno Formation is gradational and consequently, it is difficult to make a sharp division between these two Formations. Within the project area the Elliot Formation is exposed in all major drainage systems. The thickness of the Formation may range from 100 to 300 metres.

### 4.2.3 Clarens Formation

The Clarens Formation is the youngest sedimentary deposit in the Karoo Basin and was formerly called "Cave Sandstone". In Lesotho, the name Clarens Formation is used, together with the names Cave Sandstone, for the highest massive sandstone in the Clarens Formation, and "transition Beds" for that part of the Clarens Formation situated below the Cave Sandstone. As indicated by the term "Transition Beds", the contact between the Clarens Formation and underlying Elliot Formation is gradual and difficult to define. In the project area the "Transition Beds" are composed of red, and greenish, soft siltstones , alternating with more compact very fine-grained sandstone and siltstone beds. The thickness of the "Transition Beds" may range from 30 to 120 metres. The Cave Sandstone consists of massive, cliff-forming, creamy white, fine-grained sandstones and silt stones. Its thickness may vary from less than 1 metre to 200 metres.

## 4.3 Drakensberg Group

The Drakensberg Group, referred to as Lesotho Formation, consists of a succession of fissure-fed basalts. The basal part of this Formation commonly shows intercalations of sedimentary or volcanic origin. Within the project area the Lesotho Formation may reach a thickness of 900 metres. However, since the area where drilling takes place does not include the area where the Lesotho Formation outcrops, this Formation is not relevant to the present groundwater study.

## 4.4 Dikes and Sills

The volcanic fissures, called dikes, responsible for the outpouring of the basaltic lavas of the Lesotho Formation, are a very prominent feature in the whole of the Karoo Basin and are referred to as Karoo Dolerites. Dikes may cut across all geological units in Lesotho while others die out in the basalts. Dikes in Lesotho and in the project area may range in thickness from less than 1 metre to over 50 metres but typically are in the 2 to 20 metre range.

The smaller dikes are usually doleritic or basaltic whereas the wider dikes contain mostly dolerite and gabbro. At least two swarms of dikes occur in Lesotho. The main trends are north-west to south-east and north-east to south-west. Most of the dikes identifiable on aerial photos have been indicated on geological and topographical maps. However, in many occasions, dikes may be "buried" and are not visible. Most of the dikes are vertical or sub-vertical, but some dikes show a significant dip.

The occurrence of sills, intrusions along bedding planes, appears to be mainly limited to the Burgersdorp Formation and the Molteno Formation.

# 5. HYDROGEOLOGY

## 5.1 Introduction

Despite the fact that in recent years a large emphasis has been placed on developing groundwater resources for village water supplies, only a few hydrogeological studies have been undertaken in Lesotho.

The most significant studies of a hydrogeological nature have been done by Bonney (1974, 1975a,b,c,d,e).

Since 1983 the "Italian Groundwater Project" (Ministry of Water, Mines and Energy) has been involved in solving local groundwater problems and prepared reports on their investigations (see Section 11, References). However, no site specific studies were carried out in the Taung Phamong Rural Development Project area.

The Taung Phamong Rural Development Project has been successful in providing groundwater supplies but prior to 1988 generated little hydrogeological information and documentation. It should be noted, however, that generating such information was not a primary objective of its village water supply program. Since 1988 more emphasis has been placed on collecting hydrogeological data. A program for systematic collection of lithological data from the boreholes has been put in place. In addition, water level data are collected from observation wells equipped with continuous, float-activated, recorders and from selected hand pump sites (see Section 6). Some detailed water quality data have become available and a program of collecting data on temperature, conductivity and pH at hand pump sites will be carried out in the near future.

Since many of the data are in the process of being collected, the present discussion of the groundwater resources in the project area and their characteristics is brief.

## 5.2 Hydrogeological setting of the study area.

The discussion of the hydrogeological setting of the study area is limited to that area where drilling has taken place (see Map No. 1 in back of report).

Evaluation of available data suggests that three types of aquifers can be distinguished: dike-related aquifers, non-dike type of aquifers and aquifers related to alluvial deposits in river valleys.

It is estimated that about 30 to 40 percent of the successful boreholes were completed in dike-related aquifers. The remainder of the boreholes were completed in non-dike type of aquifers and no borehole was completed in an alluvial aquifer. Consequently, the alluvial aquifers are not further discussed in this report.

### 5.2.1 Dike-related Aquifers

The following discussion on dike-related aquifers is based on discussions presented by Boehmer and Boonstra (1986, 1987), Boonstra and Boehmer (1986), and Schitz and Rooyani (1987).

Groundwater flow and the behavior of groundwater in Lesotho probably is profoundly affected by the occurrence and characteristics of dikes. The wider dikes generally tend to have a massive gabbro content and below a depth of about 10 metres are typically impermeable and act as barriers to groundwater flow. Dykes with a width in the 5 to 20 metre range are commonly, but not necessarily, fractured to a depth of 30 to 40 metres.

The fractures are often formed by contraction joints within the dike rock, due to cooling and subsequent shrinkage of the magma after intrusion. Although dikes might be highly permeable, within the study area, very few boreholes have been completed in a dike itself. As a result of contact metamorphism, the country rock adjacent to an intruding dike has been metamorphosed. Baking and subsequent cooling of the country rock immediately adjacent to a dike resulted in the forming of contraction joints. In addition, intrusion of magma may also have caused crushing of the country rock along the contact zone. Due to the numerous fractures, the metamorphosed zone immediately adjacent to the dike is highly permeable compared to the unaltered country rock.

Consequently, these metamorphosed zones are the prime target for developing groundwater supplies. The width of the metamorphosed and fractured zone may vary and depends on the type of country rock and the width of the dike. Since beyond the metamorphosed zone the country rock has not been changed structurally, the yield of wells decreases with in-

creasing distance from the dike. Consequently it is of great importance to accurately determine the width of a dike, the location of the contact zone and the width of the metamorphosed, fractured, zone.

In establishing the location of a borehole typically the "witching" method has been used. In cases of vertical or sub-vertical dikes boreholes have been drilled into one of the metamorphosed zones adjacent to the dike. The side the borehole is drilled on is commonly on the side of increasing topography. When a dike was found to be dipping, often indicated by a difference in the width of the metamorphosed zones, boreholes are located in such a way that the hole would tap the fracture zone on both sides of the dike. In these cases the dip of the dike is estimated and the borehole is drilled away from the fracture zone, at a distance such that the first fracture zone would be hit at a depth of about 40 metres below the surface.

Practical experience has indicated that not necessarily both fracture zones adjacent to a dike are waterbearing or yield sufficient water for installation of a hand pump. Also, it appears to be not uncommon that when drilling in the metamorphosed zone moving the location of the borehole by a few decimetres may make the difference between a poor or good producing well.

The aquifers formed by the fractured metamorphosed zones form linear, narrow strip aquifers. The lateral extent of such aquifers depends on the length of a dike and on the lateral hydraulic continuity of the fractured zone. In most cases the dike-related type of aquifers are semi-confined (i.e., the water level rises above the zone at which water initially was struck).

### 5.2.2 Non-dike Related Aquifers

The majority of the boreholes drilled in the project area have been completed at varying depth in the different stratigraphical formations, without encountering dolerite.

Very few data exist on the hydraulic properties of the various lithological units. Bonney (1975b, p. 21) provided the following mean values of porosity for unweathered sandstone samples:

Clarens Formation sandstone:
n = 23% (3 samples)

Elliot Formation sandstone:
n = 21% (4 samples)

Molteno Formation sandstone:
n = 14% (3 samples)

Mudstone:
n = 9% (1 sample)

According to Schmitz and Rooyani (1987, p. 60), the Clarens Formation has an average porosity of 2 percent. While there is a large difference in the values reported for the porosity of sandstones in Lesotho, these values fall within the porosity range of 5 to 30% which is generally assumed to be representative for sandstones (Freeze and Cherry, 1979, p. 37). Reliable data for hydraulic conductivities are not available for the sandstones, mudstones and siltstones in Lesotho. The hydraulic conductivity of unfractured sandstones may range from $10^{-4}$ to $10^{-9}$ m/s. Unfractured mudstones, siltstones and shales likely will have a hydraulic conductivity of less than $10^{-9}$ m/s (Freeze and Cherry, 1979, p. 29). The hydraulic conductivity of fractured rock might be significantly higher than the values indicated.

The fact that so many boreholes have been successfully completed in non-dyke environments suggests that either significant differences in hydraulic properties exists related to differences in lithology or that there is a significant secondary permeability. Since there is little evidence that the occurrence of waterbearing zones is strictly related to differences in lithology and because of the low hydraulic conductivity of the unweathered and unfractured rocks, the existence of significant secondary permeability is implied. The secondary permeability is considered to be the result of fractures or fracture zones.

The origin of these fractures is not known and may be due to several causes. These causes may include: fracturing induced by doming as result of intruding silts, fracturing due to consolidation of sediments and fracturing caused by tectonics.

The distribution of the successful boreholes and water level data both indicate a random distribution of these fracture zones. The effect of this random distribution is that within a stratigraphical unit aquifer zones may occur at different levels. Little is known about the lateral continuity of these aquifer zones. In some cases water level data indicate that boreholes have been completed in the same aquifer zone while in other cases there appears to be little or no hydraulic continuity between aquifer zones, even within the same geological unit in a small area.

As with dike-related aquifers, aquifer zones related to fractures or fracture zones likely form linear, narrow strip aquifers. In most cases these type of aquifers are semi-confined.

## 5.3 Recharge and Discharge

All groundwater flow in Lesotho originates from precipitation that infiltrates to the water table, moves downward and laterally under influence of gravity, and eventually discharges back to the ground surface at some point of lower elevation.

Recharge to the water table is likely a complex process and the

amount of recharge and its distribution will be highly variable.

It depends on factors such as: precipitation and evapotranspiration, types of soils and infiltration rates, thickness of weathered zone and topography.

Groundwater flow in the study area is probably highly complex. It is controlled by numerous factors, such as: amount and distribution of recharge, topography, presence of permeable and impermeable dikes, distribution of lithologically controlled permeability and distribution of fracture zones.

The relatively permeable dikes and fracture zones likely act as conduits for groundwater flow, draining the adjacent less permeable country rock. This close relationship between these permeable zones and the country rock has significant implications for understanding the groundwater regimes when such a permeable zone is stressed by pumping. Although relatively permeable and as such capable of transmitting large amounts of water, the amount of water which can be withdrawn from such a zone itself is small. This is illustrated by considering the following equation:

$$Q = A \times H \times S$$

where:

- Q = volume of water ($m^3$)
- A = surface area of aquifer ($m^2$)
- H = drawdown (m)
- S = specific storage coefficient (dimensionless)

For example, if an aquifer is 1000 m long and 5 m wide, then Q amounts to 50 $m^3$ per metre drawdown, when S is taken to be 0.01. Although there are no data for the specific storage coefficient, the assumed value is probably a reasonable estimate for the long-term specific storage coefficient.

This example indicates that much of the water stored in the aquifer would be pumped out in a matter of hours or days, depending on the pumping rate. Consequently, the sustained yield of a well in such an aquifer will have to come from the country rock. The long-term sustained yield of a well completed in such narrow linear aquifers will depend on the capacity of the country rock to transmit water to the fracture zone and on the recharge to the country rock. Pumping from a well in a narrow linear aquifer will result in elongated drawdowns in the aquifer, extending over large distances from the production well. Within the country rock a pseudo radial flow pattern toward the aquifer is created (Boehmer and Boonstra, 1987). If pumping exceeds the amount of flow from the country rock into the aquifer zone, a continuous lowering of the water level in both the aquifer zone and the adjacent country rock can be expected. In this case the hydraulic properties of the country rock would be the limiting factor. However, even if the country rock would be capable of transmitting sufficient water to the aquifer, the water level in the country rock and aquifer would also continuously decline if pumping exceeds recharge into the country rock. In contrast, if pumping is less than the potential flow from the country rock into the aquifer or less than the recharge into the country rock, water levels would decline but stabilize.

Groundwater is discharged in the form of springs. The pattern of springs and spring lines appears to be closely related to the lithology of the geological units and to lithological boundaries (Bonney, 1975d). For example, the base of the Molteno Formation forms a springline and springs discharge throughout this Formation. In contrast, very few springs appear to be related to the Elliot Formation. This would suggest, in a cursory way, that recharge into and flow through the Molteno Formation is greater than compared to the Elliot Formation.

The fact that springs and spring lines exist and that discharge from springs may vary with seasons merely indicates that recharge occurs and that there is a dynamic equilibrium with climate. Withdrawal of groundwater affects the natural status of this dynamic equilibrium. It typically results in a new equilibrium in which water levels will be lower and in which discharge from springs will be less.

# 6. GROUNDWATER LEVEL MONITORING NETWORK

## 6.1 Introduction

As indicated in Section 5.3, groundwater regimes in the project area can be expected to be in dynamic equilibrium with climate and groundwater withdrawals. An insight in the status of this equilibrium is obtained by systematic measurement of the water level in selected boreholes, or in boreholes specifically constructed for water level observations.

Bonney (1975a) documented the establishment, in 1972, of a network of recording and non-recording observation wells and a program of measuring discharges for selected springs. This network covered the whole of Lesotho but within the study area included only a spring at Tsoloane. The present status of this network is unknown and the only available data for this network appear to be those published by Bonney (1975a,e).

Because of the increasing importance of groundwater as a water supply source and the lack of information on the behavior of groundwater regimes, the establishment of a groundwater level monitoring program in the project area was given a high priority.

## 6.2 Objective of Groundwater Level Monitoring Network

The objective of the groundwater level monitoring program is:

- to obtain reliable information on the nature and magnitude of groundwater level fluctuations in the study area and to qualitatively relate these fluctuations to climate (i.e, precipitation) and groundwater withdrawals.

Implicit to designing the network and defining its objective is that the relationship between climate and water level fluctuations can only be assessed qualitatively since it would be very difficult to obtain quantitative data on the amounts of recharge.

The groundwater level monitoring program described in this report is designed to:

- provide an insight into the response of the water level to rainfall events and periods of rain. In other words, providing information on the recharge process and occurrence of recharge.
- provide information on the long-term behavior of the water level in aquifers which are stressed by pumping. This information is particularly relevant to assess the impact of droughts on groundwater supplies.

## 6.3 Design of Network

Based on the geological and hydrogeological setting of the study area it was decided to set up a network consisting of observation wells equipped with continuous, float-activated, recorders and sites for monthly point-water level measurements.

Providing coverage for the entire study area, observation wells would have to be constructed in both dike and non-dike type of aquifers. In deciding the location of the wells, the expected difference in the amount of groundwater withdrawal between a hand pump and engine pump site also had to be taken into account.

The six observation well sites selected on the basis of the site selection criteria outlined above are listed in Table 2.

The boreholes for the observation wells were drilled in the winter of 1988 and recorders were installed in the period September 26 - 28, 1988. Because of reliability and ease in operation and maintenance, the observation wells have been equipped with Stevens, Type F, Model 68, metric, water level recorders. These float-activated recorders are driven by a battery powered Stevens Quartz Multispeed Timer. At each observation well site a structure was built out of concrete blocks to protect the recorder.

To obtain accurate information on volumes of water withdrawn from the aquifer in which an observation well was completed, flowmeters were installed on hand or engine pumps of nearby boreholes which also were completed in the same aquifer.

The location of the observation well sites is shown on Map No. 1 (in the back of report). Borehole data for each observation well and detailed location maps of observation wells and nearby boreholes are presented in Appendix C. A typical observation well site and

**Table 2.**
**Listing of observation wells sites, type of aquifer and method of nearby groundwater withdrawal.**

| Village Name | Aquifer Type | Method of nearby withdrawal |
|---|---|---|
| Village of Ha Mokoroane | dike-type | hand pumps |
| Village of Meeling | non-dike type | hand pump |
| Village of Siloe | dike-type | engine pump |
| Village of Brakfontein | dike-type | hand pumps |
| Village of Setotoma | dike-type | engine pump |
| Village of Ha Theka (Village of Holy Cross) | non-dike type | hand pump submersible |

recorder set up are shown in Figures 5 and 6, respectively.

To measure the precipitation at each well site, a Sierra-Misco, Model 2501, rain gauge was installed close to the observation well housing. This type of rain gauge has a 20.32 cm diameter orifice and a tipping bucket mechanism which switches after every millimeter of precipitation. The rain gauges were modified and equipped with a counter to facilitate recording amounts of precipitation. The 12.7 cm diameter rim of standard rain gauges in Lesotho is set at a height of 1.20 m above ground level (Ministry of Works and Communication, 197-.). However, because of the height of the recorder housings, the rim of the rain gauges at the observation well sites had to be set at 1.50 m above ground.

To augment the data to be obtained from the observation well sites, 11 additional sites were selected for monthly measurement

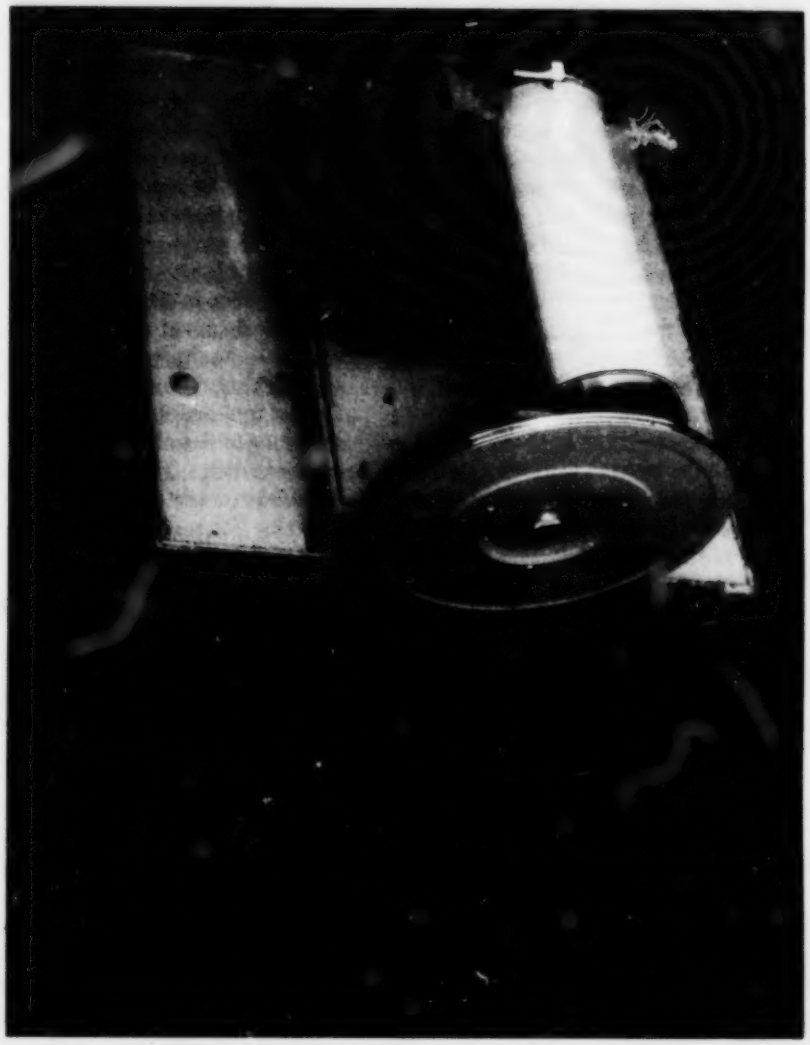

**Figure 5. (Top) Typical observation well site.**

**Figure 6. Typical recorder installation.**

**Table 3.**
**Listing of sites selected for measurement of monthly point water level**

| Village Name | Borehole Number | Aquifer Type |
|---|---|---|
| Kobo Tsoeu (Ha Malebanye) | No. 1 | non-dike |
| Mesitsaneng | No. 4 | dike |
| | No. 20 | dike |
| Ha Sekoati | No. 6 | non-dike |
| Ha Theko | No. 2 | dike |
| Rabele | No. 3 | non-dike |
| Khitsane (Mokhethi) | No. 7 | dike |
| Ha Panta | No. 3 | non-dike |
| Maseruoe | No. 1 | non-dike |
| Tsoloane | No. 1 | dike |
| Meriting | No. 2 | non-dike |

of the water level (Table 3). The main criterion for selecting these sites was that the well had to have a quick response time, allowing measurement of the "true" static water level without having to wait for a long period of time for the water level to recover in case the well was pumped just prior to a measurement. Secondly, to reduce travel time, the site had to be easily accessible from the main roads in the project area.

The location of these 11 monitoring sites is shown on Map No. 1 (in back of report). Available data for these boreholes are presented in Appendix C.

## 6.4 Groundwater Level Fluctuations

A groundwater level is never at rest due to a variety of influences, both natural and man-made. At any given time a groundwater level can be considered the result of superposition of short-term fluctuations superimposed on seasonal water level changes, superimposed on long-term fluctuations.

Long-term fluctuations of groundwater levels, extending over periods of several years or more, are the result of alternating series of years in which recharge is above or below average. Because the annual precipitation pattern in Lesotho shows long spells of "wet and "dry" years (see Section 2), it is implied that the network of observation wells will have to be operated for a long period of time before the impact of these alternating spells on groundwater can be fully assessed. Seasonal fluctuations are caused by the distribution of recharge within a year. Analysis of seasonal fluctuations will provide information on the recharge process and when it occurs.

Natural short-term groundwater level fluctuations include water level fluctuations due to atmospheric pressure changes and due to earth tides. Changes in atmospheric pressure may produce sizable water level changes in wells completed in semi-confined aquifers. The relation is inverse, that is, increases in atmospheric pressure produce decreases in water level, and vice versa. Bonney (1975e, p. 21) indicates that several observation wells showed response to barometric pressure changes but did not provide any information on the magnitude of these water level fluctuations.

Earth tides, resulting from the attraction exerted on the earth's crust by the moon and, to a lesser extent the sun, may cause diurnal and semi-diurnal water level fluctuations. Bonney (1975b, p. 21) indicates that the water level in several observation wells showed a response to semi-diurnal earth tides. A well near Roma was reported to show water level fluctuations due to earth tides with an amplitude of 1.5 cm.

The most obvious man-induced water level fluctuations are those related to groundwater withdrawals. The nature and magnitude of these man-made fluctuations depends on use pattern, the hydraulic properties of the aquifer and on the distance between the production well and the observation well.

Since most of the observation wells constructed in the project area are located close to production wells, the influence of withdrawals on the water level in the observation wells typically will be large. The short-term fluctuations due to barometric pressure changes and earth tides will be "obscured" by these large man-induced fluctuations. In addition, recorders near production wells have been equipped with 1:20 gear ratios. Such a gear ratio does not provide sufficient resolution for a further investigation of these short-term fluctuations. While of some scientific interest, analyses of fluctuations due to barometric pressure changes and earth tides are beyond the objective of the network.

The short-term groundwater level fluctuations caused by atmospheric pressure changes, earth tides and pumping are eliminated by calculating median monthly water levels. The median monthly water level is defined as: (maximum depth to water + minimum depth to water)/2. Plots of median monthly water levels will provide the best insight in the seasonal and long-term fluctuations and the impact groundwater withdrawals may have on groundwater levels.

## 6.5 Collection of Initial Water Level Records

Since the nature and magnitude of water level fluctuations in the project area were unknown when the recorders were installed, all recorders initially were equipped with gears such that every 20 cm of water level change was recorded on the recorder chart as a 1 cm change.

To provide for the best possible resolution of the water level fluctuations, gear ratios were changed

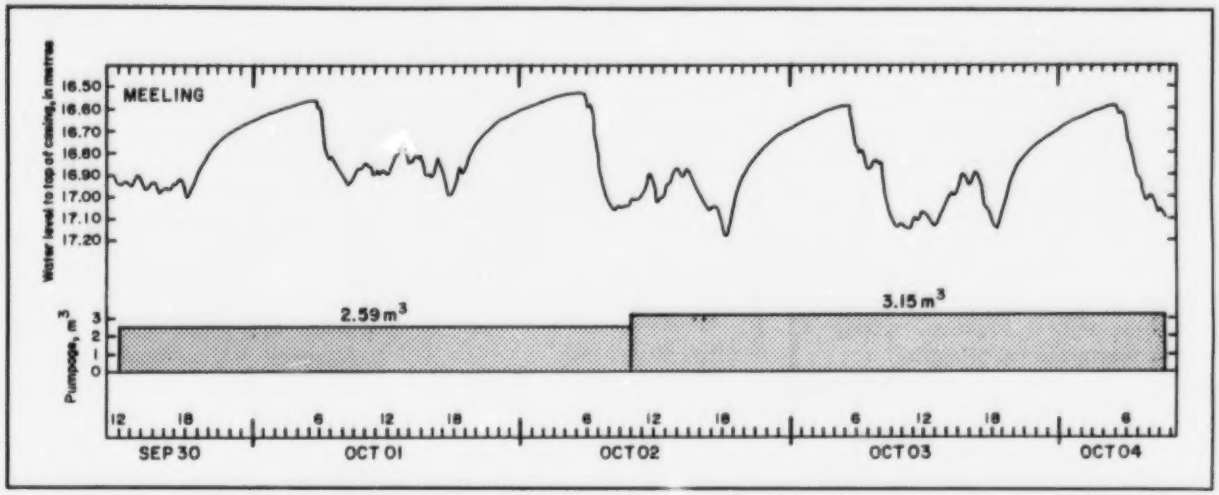


**Figure 7. Hydrograph for Meeling observation well for period September 30 - October 04, 1988.**

after records became available and if a change was considered necessary (see Appendix C for final gear ratio selection).

To obtain detailed information on the nature and magnitude of water level changes and the time at which these occurred, the Quartz Multispeed Timers initially were set to two days. On October 7, 1988, all the timers were set to 32 days, the selected time interval for changing of the recorder charts.

Parts of the hydrographs obtained from the observation wells in the period September 26 - October 9, 1988, are discussed in the following sections.

No data have been obtained from the sites where the water level will be measured on a monthly basis.

## 6.6 Discussion of Initial Water Level Records

### 6.6.1 Siloe Observation Well

During the period of observation, the observation well flowed since the pump on the Siloe production well had been defective for several weeks. Consequently, no meaningful records were obtained from this well.

### 6.6.2 Meeling Observation Well

The hydrograph from the Meeling observation well (Figure 7) shows pronounced daily water level fluctuations with an amplitude ranging from 41 cm to 65 cm. These fluctuations are due to pumping from hand pump Meeling No. 6 which is located at a distance of 4 m from the observation well (see Appendix C). Typically, withdrawing water from the hand pump starts at about 05.30 hrs. The water level declines from 05:30 hrs until about 09:00 hrs. From 09:00 hrs to about 13:00 hrs the hand pump is used less but a sufficient amount of water is withdrawn so that decline due to withdrawal and recovery is about balanced. The hand pump is used intermittently from 13:00 hrs to about 16:30. The water level declines again from about 16:30 hrs till about 18:30 hrs due to increased use of the hand pump. From about 18:30 till 05:30 the next morning the water level recovers. It is interesting to note that at the end of each daily pumping cycle the water level has not come to a complete recovery. Typically, not obtaining complete recovery could be interpreted as a sign that more water is taken out of the aquifer then is flowing into the aquifer and toward the well site. This scenario would imply a slow, but systematic, lowering of the water level in the aquifer with time.

The initial static water level for Meeling No. 6, measured in April 1986, was 7.7 metres below ground surface (see Appendix C). During the period of observation, the water level in both the hand pump borehole and the observation well averaged about 16.9 m below ground surface. However, since there are no data as yet on the magnitude of seasonal fluctuations, it cannot be stated that the drop in water level of about 9 metres since April 1986 is attributable to groundwater withdrawal from the hand pump. If there are large seasonal water level fluctuations, which can be expected in fractured mediums, the 9 metre difference simply may reflect a seasonal difference in water level.

In contrast to the scenario of declining water levels, it also could be argued that due to pumping the drawdown has stabilized. In this case, the daily pumping cycles can be visualized as "noise" around a

more or less stabilized drawdown. In this scenario there would not be a systematic decline of the water level with time. The water level in the aquifer would be systematically lower than would be the case if there was no pumping but the water level still would follow the seasonal and long-term water level fluctuations. Only after several years of data have become available will it become evident which scenario is applicable.

### 6.6.3 Mokoroane Observation Well

The hydrograph from the Mokoroane observation well is shown in Figure 8. This hydrograph also shows definite daily fluctuations but the range is significantly smaller than is the case at Meeling. The daily water level fluctuations are in the range of 2.4 to 6.1 cm. The hydrograph shows either one or two daily peaks. One occurs between 04:00 and 06:00 hrs, the second one at about 16:00 hrs. The daily minimum water level typically occurs at about 21:00 hrs. It is suspected that these daily fluctuations are related to pumping from Mokoroane No. 4, located at a distance of about 100 metres from the observation well (see Appendix C). However, these fluctuations may also reflect earth tides and barometric effects.

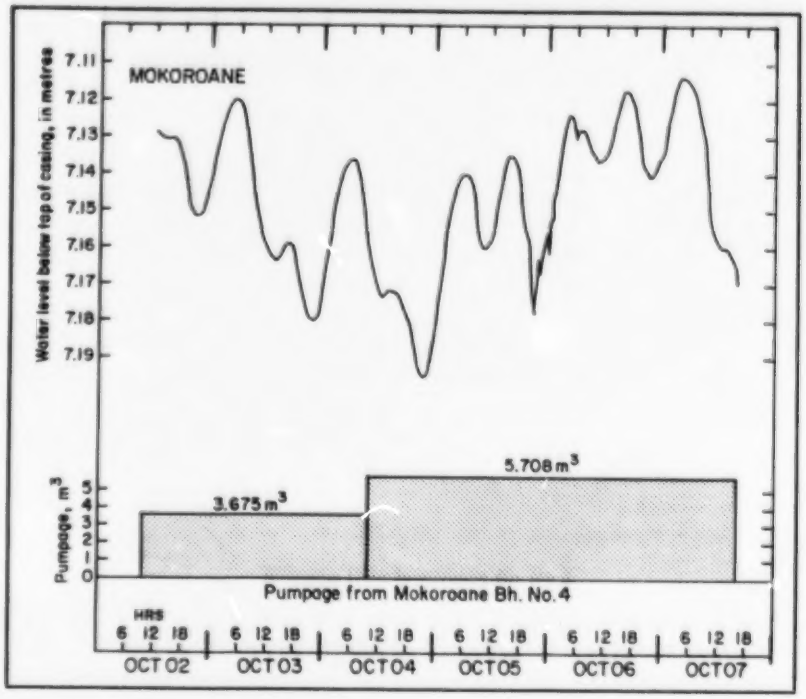


**Figure 8. Hydrograph for Mokoroane observation well for period October 02 - October 07, 1988.**

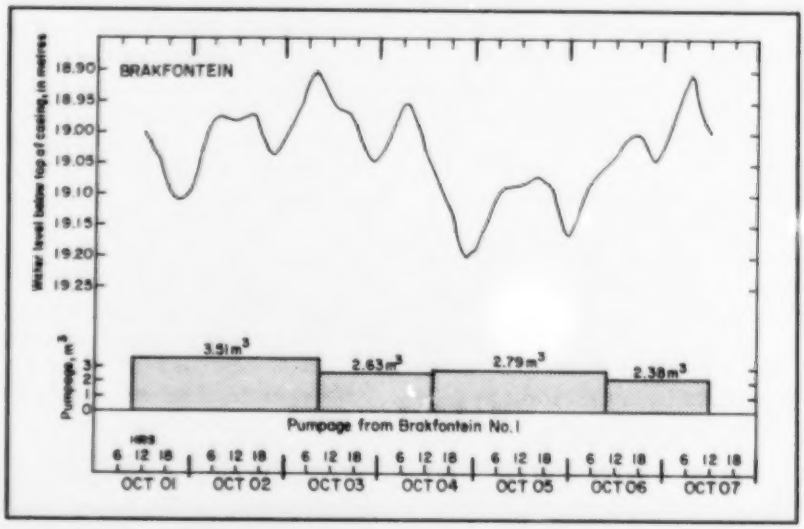


**Figure 9. Hydrograph for Brakfontein observation well for period October 01 - October 07, 1988.**

### 6.6.4 Brakfontein Observation Well

The hydrograph for the Brakfontein observation well is shown in Figure 9. This hydrograph also shows daily, cyclic, fluctuations which are probably due to pumping from two nearby hand pumps (see Appendix C). A daily minimum water level typically occurs at about 21:00 hrs, followed by a recovery of the water level. The daily maximum generally occurs between 07:00 and 08:00 hrs. Probably due to a somewhat different hand pump use pattern, there is no sharp peak on October 02, 05 and 06.

These fluctuations may also reflect the effects of earth tides and barometric tides.

### 6.6.5 Setotoma Observation Well

The hydrograph for the Setotoma observation well is

shown in Figure 10. The hydrograph shows a very pronounced drawdown of about 5 m due to pumping from the Setotoma production well, located at a distance of 5.5 m from the observation well (see Appendix C).

The Setotoma production well commonly is pumped every 4 days for 6 hours, at a rate of about 1 $m^3$ per hour. The recovery is slow and similar as was the case at Meeling, the recovery is not completed before the next pumping event.

In November 1985, the depth to water in the production well was reported to be 39.5 m. A water level measurement in October 1988 indicated that the water level was at a depth of 35.6 m (see Appendix C). The 4 metre increase at this site is in sharp contrast to the decrease in water level at the Meeling site (see Section 6.5.2).

There is no obvious cause to explain the increase but it may be related to seasonal fluctuations.

The significance of partial recoveries and the increase in water level since 1985 can only be assessed after several years of records have become available.

### 6.6.6 Holy Cross Observation Well

The hydrograph for the Holy Cross observation well is shown in Figure 11. This hydrograph also shows typical daily fluctuations due to pumping from a hand pump, located 31 m from the observation well (see Appendix C). The daily fluctuations are characterized by a daily maximum, occurring between 05:00 and 06:00 hrs. The daily minimum water level generally occurs between 09:00 and 10:00 hrs. Between about 10:00 hrs and 16:00 hrs the hand pump is used intermittently and the water level recovers. After about 16:00 there is an increased use in the hand pump and the water level declines again until about 18:30. From about 18:30 - 19:00 hrs the water level recovers until the start of the next pumping cycle.

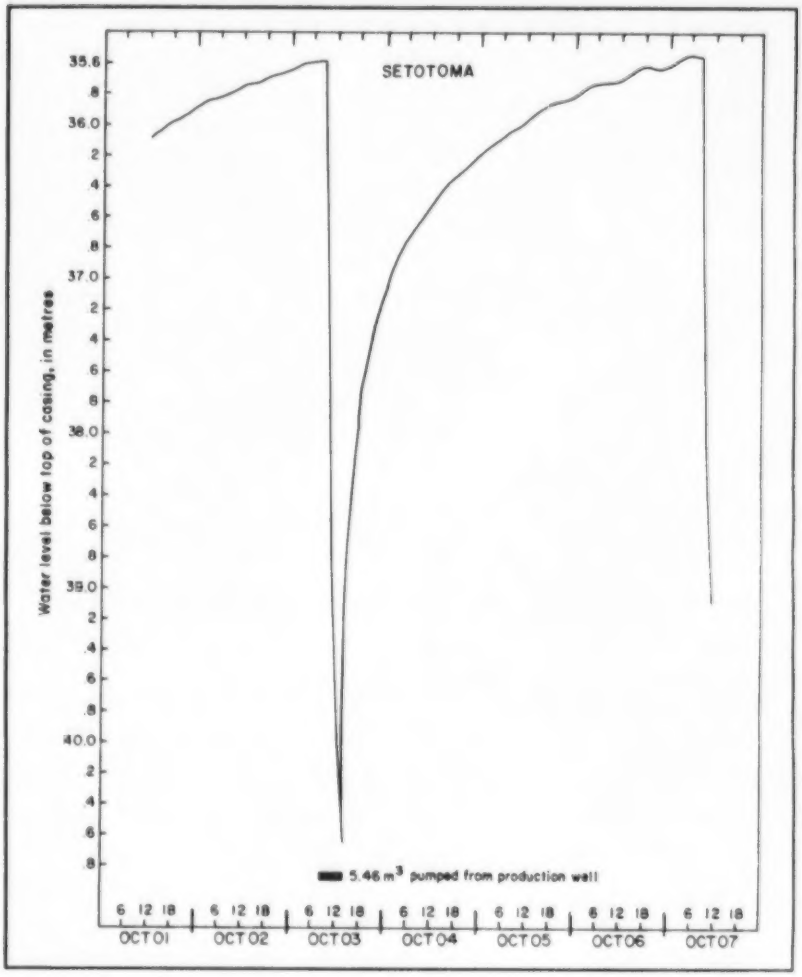


**Figure 10. Hydrograph for Setotoma observation well for period October 01 - October 07, 1988.**

The observed daily fluctuations in the water level may range from 1.4 to 1.8 metres. Similarly, as was the case at Meeling and Setotoma, the water level does not completely recover before the next pumping cycle starts. Again, the significance of the lack of coming to complete recovery can only be assessed after several years of data have become available.

It was anticipated that the pumping from the nearby borehole equipped with a submersible pump would have a significant effect on the water level in the observation well. On October 03 this well, at a distance of 26 m from the observation well and completed at about the same depth, was pumped from 11:00 till 13:00 hrs. Although a drawdown of about 5.8 m was created in this borehole, the hydrograph from the observation well showed no evidence of being affected by this pumping (see Appendix C).

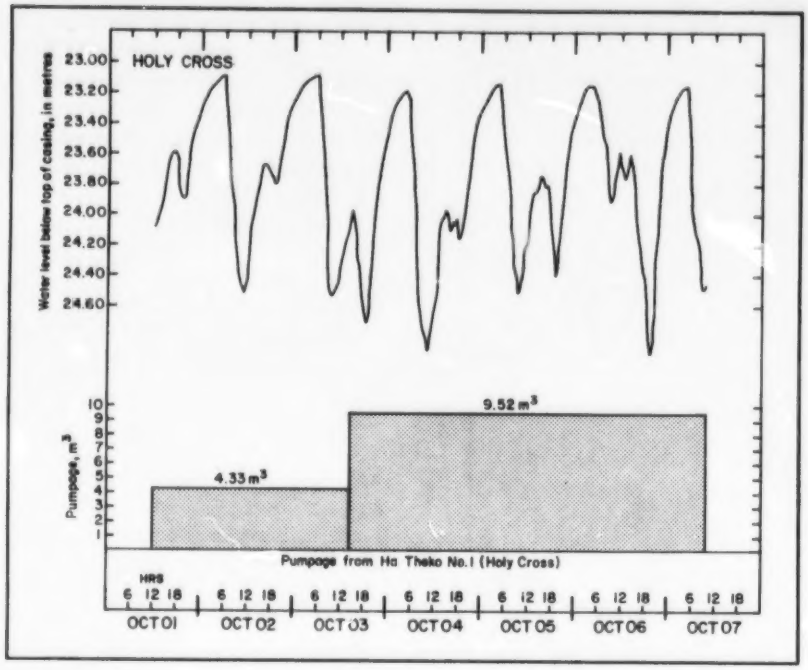


**Figure 11. Hydrograph for Holy Cross observation well for period October 01 - October 07, 1988.**

# 7. GROUNDWATER QUALITY

## 7.1 Introduction

In January 1988, six groundwater samples were collected for detailed major ion analyses and for isotope analyses since there were no water quality data available for the project area and no data have been published on the groundwater quality elsewhere in Lesotho. As sample points, the production wells nearest to planned observation wells were selected.

A program has been initiated to collect conductivity, temperature and pH data from boreholes drilled since 1987. These data will become available at a later date.

## 7.2 Major Ion Chemistry

Samples for major ion analysis were filtered in the field using Millipore filtering equipment and 0.45 micron filters. A 500 ml sample was collected for major ion analyses. A 250 ml sample was preserved with concentrated hydrosulfuric acid ($H_2SO_4$) for nutrients analyses. Another 250 ml sample was preserved with concentrated hydrochloric acid (HCl) for analysis of iron and manganese. The samples were submitted for analysis to the Analytical Laboratory of the Saskatchewan Research Council.

The results of the major ion analyses are tabulated in Table 4. and are graphically presented in Figure 12. The sum of ions shown in Table 4 is determined by addition of the concentrations of the following constituents: Ca, Mg, Na, K, $CO_3$, $HCO_3$, $SO_4$, Cl, $NO_3$ and $PO_4$.

The results of chemical analyses are considered acceptable if the error in the ion balance is less than 3%. On a Piper plot (Figure 12), the concentrations of cations and anions are expressed as percentage of the total equivalents per litre of cations and anions. Plotting analyses on Piper plots allows determination of water type and also shows the effect of mixing, if occurring.

Table 4 and Figure 12 show that, as far as the data presently available are concerned, groundwater in the project area may vary in quality, both in terms of concentration and composition. The present data indicate that the sum of ions may vary from 178 mg/L to 476 mg/L and that the water is either of the calcium/magnesium - bicarbonate or sodium - bicarbonate type. Since bicarbonate is the dominant anion, the type of water is determined by the relative concentrations of calcium, magnesium, and sodium. Both the composition and concentrations of individual constituents in a particular water sample are the result of complex geochemical processes in the soil, and between the water and the various lithological units through which it flows. An investigation of these geochemical processes is beyond the scope of the present study.

Because the amount of water quality data presently available is limited, the observed range in sum of ions and in the concentration of individual constituents probably does not represent the total range which may occur.

Since Lesotho does not appear to have groundwater quality guidelines, the Canadian water quality standards for untreated groundwater for municipal water supplies are also shown in Table 4.

It is evident from Table 4 that the quality of the groundwaters sampled is within the Canadian standards.

The chloride and nitrate concentration in the sample from Brakfontein No. 1 is somewhat higher than the concentrations observed in the other samples. However, since the number of samples is small it can not be stated with a reliable degree of certainty that the values would indicate contamination. If contaminated, its source could include sewage (human and cattle), and fertilizers.

## 7.2 Isotope Analyses

### 7.2.1 Introduction

In January 1988, samples also were taken from the same locations for enriched tritium ($^3H$) analysis and for analysis of the non-radioactive isotopes oxygen-18 ($^{18}O$) and deuterium ($^2H$). Unfiltered 1 L samples were collected in high density polyethylene bottles for enriched tritium analysis. These samples were analyzed by the Department of Isotope Research, Weizmann Institute of Science, Rehovot, Israel.

For analysis of $^{18}O$ and $^2H$, 100 ml samples were collected in glass bottles. These samples were analyzed by the Environmental Isotope Laboratory, Department

**Table 4.**
**Water Quality Data for Selected Boreholes in Taung Phamong Project Area.**

| | Brakfontein | Meeling | Siloe | Setotoma | Mokoroane | Holy Cross | Canadian Standards* |
|---|---|---|---|---|---|---|---|
| B.H. No. | 1 | 6 | | | 4 | HP | |
| Date | 880126 | 880127 | 880128 | 880126 | 880127 | 880126 | |
| Depth (m) | 60 | 53.4 | 42 | 81 | 40.4 | | |
| Temp (C) | 18 | 18 | 18 | 17.8 | 17.5 | 19 | 15 |
| pH Lab | 8.30 | 8.46 | 7.71 | 7.71 | 7.42 | 7.46 | 6.5-8.5 |
| pH Field | 8.1 | 9.0 | 7.7 | 7.9 | 7.2 | 7.8 | |
| Ca | 14 | 1.6 | 41 | 30 | 17 | 23 | |
| Mg | 2.1 | 0.14 | 10 | 8.3 | 6.4 | 2.1 | |
| Na | 117 | 89 | 29 | 16 | 19 | 100 | |
| K | 2.1 | 0.9 | 1.9 | 0.6 | 1.7 | 1.7 | |
| Fe | 0.02 | 0.04 | 0.018 | 0.023 | 0.018 | 0.18 | 0.3 |
| Mn | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.015 | 0.05 |
| $CO_3$ | - | 11 | - | - | - | - | |
| $HCO_3$ | 281 | 185 | 229 | 152 | 129 | 330 | |
| $SO_4$ | 12 | 10 | 13 | 9.4 | 1.6 | 12 | 500 |
| Cl | 37 | 11 | 4.4 | 1.9 | 1.5 | 3.9 | 250 |
| $NH_4$-N | 0.09 | 0.06 | 0.06 | 0.03 | 0.04 | 0.12 | |
| $NO_3$-$NO_3$ | 10.6 | 3.28 | 1.73 | 4.87 | 1.73 | 0.04 | 40 |
| $PO_4$-$PO_4$ | 0.03 | 0.18 | <0.03 | <0.03 | <0.03 | <0.03 | |
| P, Total | 0.07 | 0.06 | 0.04 | 0.05 | 0.05 | 0.03 | |
| C, Total | 61 | 44 | 48 | 33 | 28 | 71 | |
| C, Inorganic. | 54 | 38 | 44 | 25 | 22 | 68 | |
| C, Organic. | 7 | 6 | 4 | 8 | 6 | 3 | |
| Si | 4 | 3.1 | 4 | 5.9 | 5.6 | 3.6 | |
| Cond. | 578 | 378 | 388 | 271 | 216 | 523 | |
| Sum Ions | 476 | 312 | 330 | 223 | 178 | 473 | 500 |
| E (%) | 0.46 | 0.20 | 0.03 | 1.26 | 0.61 | 0.48 | |
| T.A. | 230 | 172 | 188 | 124 | 106 | 270 | |
| P.A. | | 9.4 | | | | | |
| T.H. | 44 | 4.6 | 144 | 109 | 69 | 66 | |

Notes:
All values are in mg/L, except for Conductivity (Cond.) which is in µS/cm @ 25 C, and pH.
T.A. is Total Alkalinity as $CaCO_3$
P.A. is Phenol Alkalinity as $CaCO_3$
T.H. is Total Hardness as $CaCO_3$
E. is error in balance
* Canadian Water Quality Guidelines, Environment Canada, 1987

of Earth Sciences, University of Waterloo, Waterloo, Canada.

### 7.2.2 Tritium Analysis

Testing of thermonuclear devices in the atmosphere during the period 1952 - 1969 introduced significant amounts of tritium into the atmosphere. Consequently, precipitation, and thus the recharge derived from this precipitation, showed concentrations of tritium significantly higher than prior to 1952. Maximum tritium concentrations in precipitation occurred in 1963, since when they have decreased. In the southern hemisphere the tritium concentration were significantly lower than in the northern hemisphere, due to the higher ratio of oceanic area to land area. Also, at any given latitude the concentration of tritium in precipitation at stations near the coast are lower than those inland because of dilution from oceanic water vapour, which is low in tritium (Payne, 1975).

In hydrogeology, analyses of groundwater for concentrations of tritium are used to determine whether or not the water originated prior or after 1953. Post-1953 water is generally referred to as modern water or bomb tritium water. In analysis, the concentration of tritium is expressed in tritium units (TU). One TU is the equivalent of 1 tritium atom in $10^{18}$ atoms of hydrogen. The half-life of tritium is 12.3 years.

In 1963 the tritium concentration of precipitation in Lesotho may have been in the 18 - 32 TU range (UNESCO, 1977, Figure 10.2.2.1b). Taking into account the half-life of tritium, this would imply that unmixed 1963 recharge water would have a 1988 tritium concentration in the order of 4 to 8 TU.

The results of the enriched tritium analyses are listed in Table 5.

The results indicate that water from Brakfontein No.1, Setotoma and Meeling No. 6 probably is a mixture of modern water and pre-1953 water.

Water from Holy Cross and Mokoroane No. 4 probably is also a mixture but has a greater component of pre-1953 water. Water from the Siloe production well appears to be mostly pre-1953 water. These data suggest that at least some recent water may have entered the aquifers in which the observation wells have been completed, with the possible exception

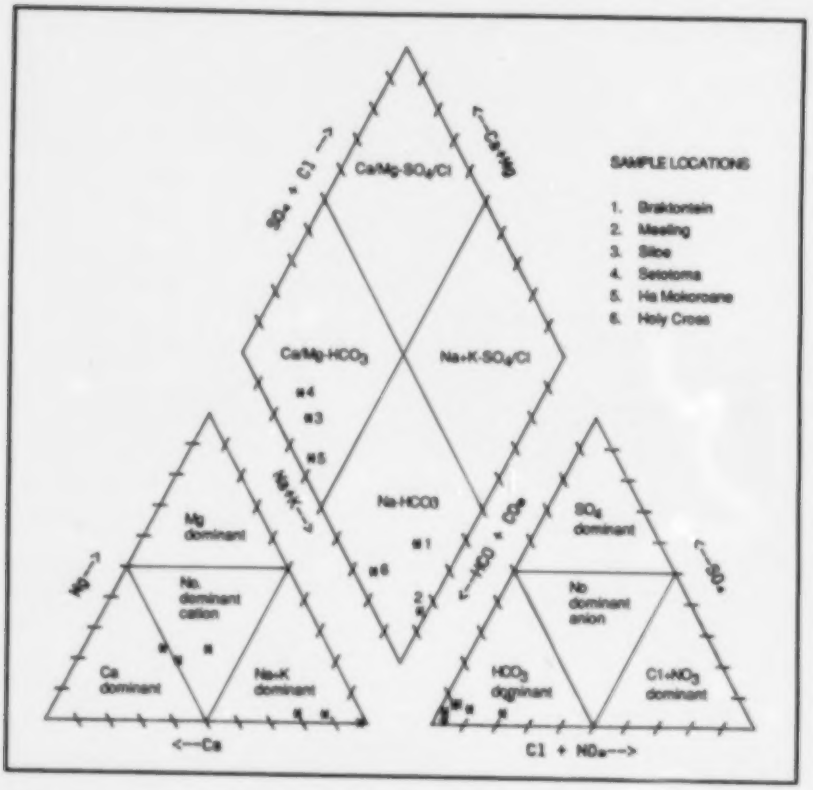


**Figure 12. Piper-Plot of water quality data from selected boreholes in Taung Phamong Project Area, Lesotho.**

of the aquifer at the Siloe observation well site.

### 7.2.3 Oxygen and Deuterium Analysis

The measurement of the isotopic ratios $^{18}O/^{16}O$ and $^{2}H/^{1}H$ in groundwater samples, relative to a standard, provides information on its origin and the period of recharge. For $^{18}O$ and $^{2}H$ the reference is Standard Mean Ocean Water (SNOW) and the results are expressed as parts per thousand ($^{0}/00$) difference from the standard. The isotopic composition of SNOW is very close to the average isotopic composition of the oceans. The isotopic composition of most groundwaters very closely reflects the weighted average annual isotopic composition in the area. As a consequence, for each study area the local meteoric water line has to be established. The local meteoric water line is an equation which relates $^{18}O$ and $^{2}H$ values in precipitation for a particular location or area. Unfortunately, the local meteoric water line for the Taung Phamong study area is not established and consequently, the data shown in Table 6 can not be interpreted. However, since there is sufficient differentiation in the results it is suggested that isotope data might help to better understand the groundwater flow systems.

**Table 5.**
**Tritium concentration in groundwater from selected boreholes in Taung Phamong Project area.**

| Borehole Name | Tritium (TU) |
|---|---|
| Brakfontein No. 1 | 1.7 ± 0.2 |
| Setotoma | 1.7 ± 0.2 |
| Meeling No. 6 | 1.6 ± 0.2 |
| Holy Cross | 0.8 ± 0.2 |
| Mokoroane | 0.3 ± 0.1 |
| Siloe | 0.1 ± 0.2 |

**Table 6.**
**Oxygen-18 and deuterium data for groundwater from selectedboreholes in the Taung Phamong Project area.**

| Borehole Name | Delta-$^{18}O$ | Delta-$^{2}H$ |
|---|---|---|
| Brakfontein No. 1 | -3.71 | -40.1 |
| | -3.69 | -38.9 |
| Siloe | -2.54 | -30.2 |
| | -2.78 | -36.1 |
| Mokoroane No. 4 | -4.34 | -30.8 |
| | -4.26 | -30.9 |
| Holy Cross | -4.54 | -52.1 |
| | -4.30 | -47.2 |
| Meeling No. 6 | -4.57 | -63.9 |
| | -4.39 | -59.3 |
| Setotoma | -3.92 | -26.8 |
| | -3.99 | -25.6 |

# 8. TRAINING

An important component of the second visit to the project area was training of local personnel in the operation and maintenance of the water level recorders and rain gauges, and in the processing of the data.

Personnel of Village Water Supply (VWS), Mohale's Hoek, and project staff were provided with an extensive operating and maintenance manual for the instruments (Maathuis, 1988b). Installation of the instruments was done together with personnel of VWS and they were also directly involved in the initial frequent changing of the recorder charts (Figure 13). VWS personnel will be responsible for the monthly changing of the recorder charts and for collecting water level, flow meter and water quality data from the boreholes near observation wells. In addition, VWS will carry out the monthly water level measurement at the 11 sites which are not equipped with a continuous recorder. The data collected in the field are recorded on prepared data sheets and together with the recorder charts are filed in the project office.

Since the project office is equipped with an Olivetti M24 personal computer, TWIN spreadsheet programs for storage and retrieval of field data were set up with the project staff (Figure 14).

Once the 1988 boreholes and boreholes subsequently drilled have been equipped with hand

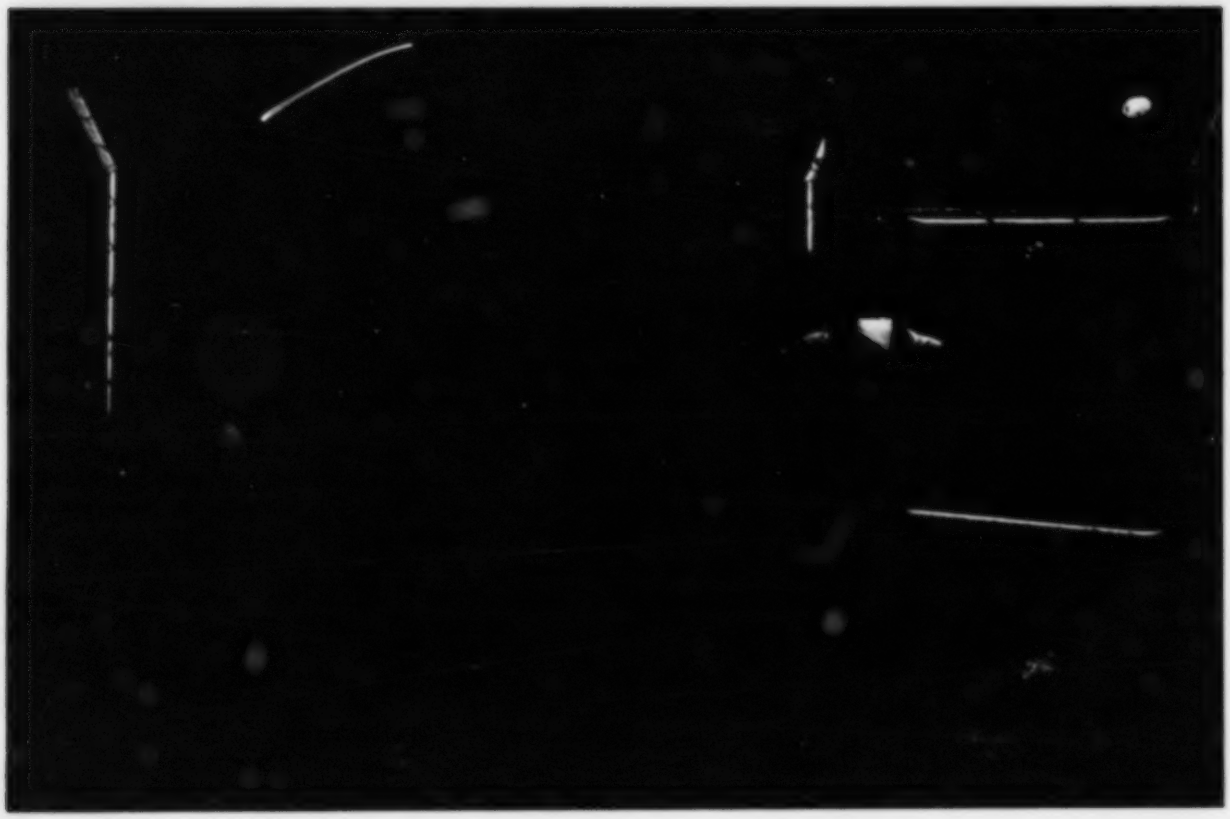

**Figure 13. Changing of recorder chart by personnel of Village Water Supply.**

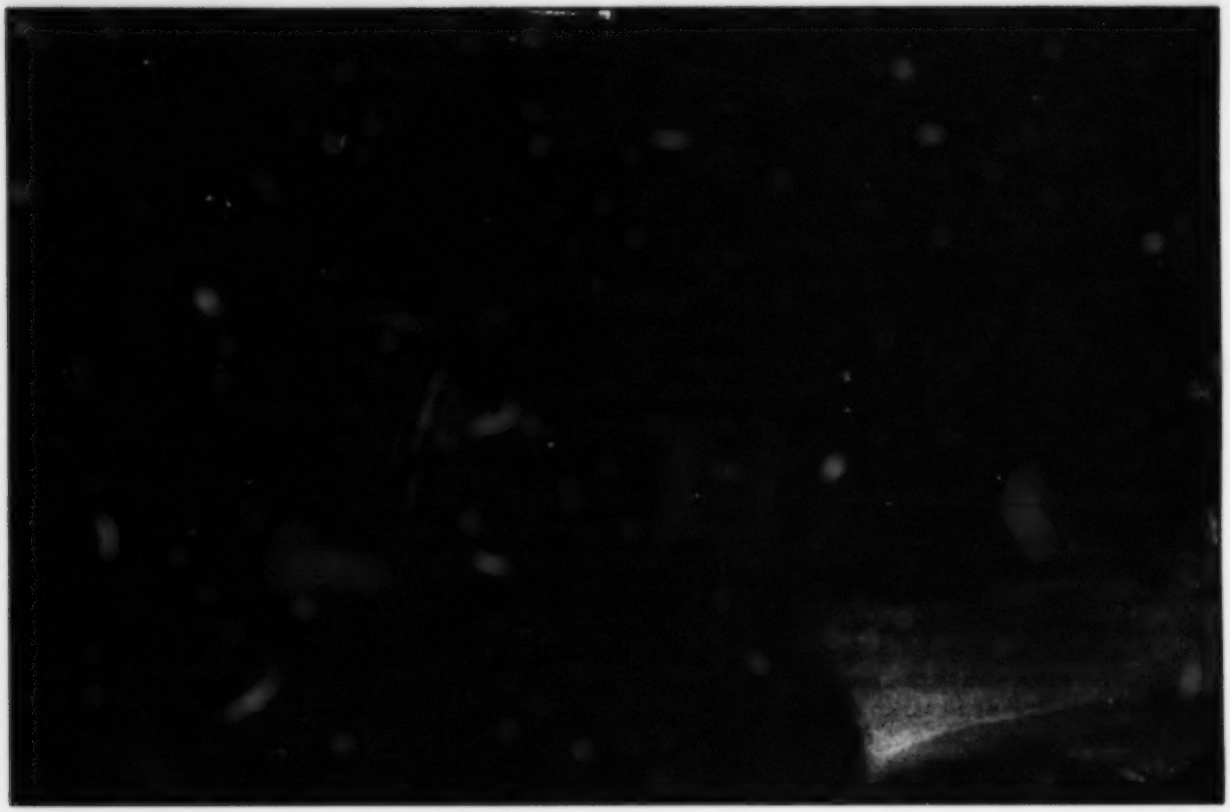

**Figure 14. Computer processing of groundwater data.**

pumps, VWS personnel together with project staff will collect and process water temperature, pH and electrical conductivity data.

At the end of the project, originals of all data collected from the groundwater level network and all water quality data will be handed over to Village Water Supply, Mohale's Hoek, for permanent storage.

# 9. CONCLUSIONS

1. The Taung Phamong Rural Development Project has achieved a high rate of success in locating and drilling boreholes for developing groundwater as a water supply source for villages.

2. The special emphasis placed, since the start of the 1988 drilling program, on collecting hydrogeological data will greatly contribute to a better understanding of the groundwater resources in the project area as well as in other areas in Lesotho with a similar hydrogeological setting.

3. Basically two types of aquifers can be distinguished in the project area: dike related and non-dike related aquifers. Both these type of aquifers can be visualized as fractured, permeable, narrow strip aquifers of varying extent, bounded by less permeable country rocks. The aquifers commonly are semi-confined.

   Although groundwater resources have been developed virtually everywhere throughout the project area, there is no evidence of the existence of regional aquifers. However, existence of significant secondary permeability in the country rock is implied.

4. Initial water level records from observation wells show that the water level in most of the observation wells is affected by pumping. Some observation wells show water level fluctuations which may be due to earth tides and barometric pressure changes. The water level records from observation wells near hand pumps also provide information on the pattern of hand pump use.

   Within several years, information will become available on the relative magnitude of recharge and when it occurs, and on the impact of groundwater withdrawals. However, because of the long- term "wet" and "dry" spells, it may take several decades of monitoring before the impact of these spells on groundwater levels can be fully assessed.

5. Although only a small number of analyses is available, the quality of groundwater appears to be good, when compared to the Canadian Water Quality Standards for untreated groundwater for municipal supplies. The water quality data to be collected in the near future will provide more extensive data on the quality of the groundwater.

# 10 RECOMMENDATIONS

1. Data collected from the groundwater level monitoring network should be reviewed annually.
2. Prior to the end of the Taung Phamong Rural Development Project all groundwater related data collected during the lifetime of the program should have been fully documented and evaluated.
3. High priority should be given to the development of DBASE III programs for storage and retrieval of the borehole and water level data.
4. Water samples for detailed major ion analysis should be collected from the boreholes near the observation well sites and from the 11 sites selected for monthly measurement of the water level.

   An analysis should include determination of the concentration of: Ca, Mg, Na, K, $CO_3$ (if pH>8.3), $HCO_3$, $SO_4$, Cl, $NO_3$, F and pH.
5. From the 1988 boreholes and boreholes yet to be drilled the following water quality data should be collected: temperature, field pH and electrical conductivity.
6. Detailed information on the effect of hand pump usage on the water level in the Meeling, Mokoroane, Brakfontein and Holy Cross observation wells should be obtained. This information is required to better understand the degree to which the water level in these wells is affected by pumpage and by natural causes.

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Note: References marked with * are available in the library of the Ministry of Mines and Geology, Maseru, Lesotho.

# APPENDIX A

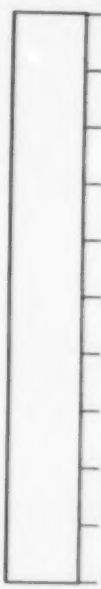
# BOREHOLE DATA SUMMARY AND BAIL TEST AND ANALYSIS FORMS

## Taung Phamong Project - Borehole Data Summary

Village Name: _____
Village Coordinates:(x) _____;
Borehole No.: _____
Topographical Map: _____
Estimated Elevation: _____m
Altimeter Reference Point: _____
Type Aquifer: _____

Project Number: _____
(y) _____
Date Drilled: _____
Geological Map: _____
Source: _____

Geological Formation: _____




### Lithology

| From (m) | To | |
|---|---|---|
| _____ | _____ | _____ |
| _____ | _____ | _____ |
| _____ | _____ | _____ |
| _____ | _____ | _____ |
| _____ | _____ | _____ |
| _____ | _____ | _____ |
| _____ | _____ | _____ |
| _____ | _____ | _____ |
| _____ | _____ | _____ |
| _____ | _____ | _____ |

Driller: _____ Geology By: _____

### Well Data

Depth Hole: _____ m
Diameter Hole: _____ mm
Type Pump: _____
Date Installed: _____
Remarks: _____

Depth Water Struck: _____m
Length casing: _____m
Bottom Pump: _____m
Porthole: Yes No

### Water Level and Test Data

Static Water Level: _____ m
Date Static Water Level Measurement: _____
Date Bail Test: _____
Average Bailing Rate: _____ L/min
Date Pump Test: _____
Pumping Rate: _____ L/min
Blow Yield: _____(L/hr)

Below: _____
Duration Test: _____min
Final Drawdown: _____m
Duration Test: _____min
Final Drawdown: _____m

### Water Quality - Field Measurements

Ph: _____ Conductivity: _____µS/cm Temp.: _____ C
Date Measurement: _____

# Taung Phamong Project - Bail Test Data and Analysis

## Well Data

Village Name: _____ Project No.: _____
Borehole No.: _____ Depth: _____ m
Depth Water Struck: _____ m Casing length: _____
Static Water Level: _____ m below ground Date: _____
Borehole Diameter: _____ mm Formation: _____

## Bail Test

| Bailing Period | | | Recovery Period | |
|---|---|---|---|---|
| TIME | DTW | BAILS | TIME | DTW |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Was well developed prior to test: Yes - No Date: _____
Was water level at static prior to bail test: Yes - No
Volume bail: _____ L
Date Test: _____ Observer: _____
Duration of Bailing (min): _____
Total Volume Bailed (L): _____
Average Bailing Rate (L/min): _____
Final Drawdown (m): _____
T - 50% Recovery (min): _____
T - 90% Recovery (min): _____

# APPENDIX B

# PRECIPITATION DATA FOR MOHALE'S HOEK

## APPENDIX B

### PRECIPITATION DATA (MM) FOR MOHALE'S HOEK, LESOTHO

| YEAR | JAN | FEB | MARCH | APRIL | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1896 | 76.2 | 66.5 | 42.9 | 65.0 | 146.6 | 47.5 | 0.0 | 109.7 | 0.0 | 8.1 | 96.5 | 326.6 | 986 |
| 1897 | 131.6 | 127.0 | 161.3 | 28.2 | 18.0 | 2.5 | 0.0 | 0.0 | 27.9 | 18.0 | 8.1 | 66.0 | 589 |
| 1898 | 405.1 | 73.7 | 65.8 | 39.1 | 26.7 | 0.0 | 0.0 | 16.8 | 17.8 | 75.4 | 88.6 | 63.5 | 873 |
| 1899 | 65.5 | 55.9 | 235.2 | 120.6 | 59.9 | 24.4 | 86.9 | 35.8 | 32.3 | 88.6 | 43.4 | 99.8 | 948 |
| 1900 | 230.6 | 103.4 | 81.3 | 67.8 | 7.6 | 20.1 | 18.5 | 29.0 | 0.0 | 36.6 | 16.0 | 139.2 | 750 |
| 1901 | 21.6 | 102.6 | 151.6 | 42.4 | 0.0 | 3.3 | 13.2 | 43.9 | 63.2 | 67.3 | 70.6 | 111.3 | 691 |
| 1902 | 74.9 | 128.5 | 110.7 | 35.1 | 6.6 | 78.5 | 4.3 | 6.6 | 97.0 | 88.9 | 24.6 | 99.6 | 755 |
| 1903 | 31.2 | 101.6 | 8.6 | 88.9 | 75.9 | 6.9 | 0.0 | 0.0 | 0.0 | 48.5 | 54.4 | 65.0 | 481 |
| 1904 | 140.5 | 67.3 | 27.4 | 18.8 | 25.4 | 7.6 | 0.0 | 16.0 | 39.6 | 46.5 | 58.2 | 82.3 | 530 |
| 1905 | 73.2 | 101.3 | 125.0 | 40.9 | 49.8 | 15.5 | 0.0 | 2.3 | 60.7 | 3.6 | 77.7 | 175.3 | 725 |
| 1906 | 172.0 | 119.6 | 33.5 | 18.0 | 24.4 | 7.4 | 0.0 | 0.0 | 65.3 | 75.9 | 102.6 | 97.3 | 716 |
| 1907 | 109.7 | 141.0 | 137.9 | 134.4 | 110.2 | 6.1 | 8.4 | 0.0 | 37.1 | 70.1 | 132.6 | 161.5 | 1049 |
| 1908 | 63.5 | 67.8 | 105.9 | 37.6 | 15.5 | 43.4 | 12.4 | 41.4 | 68.1 | 74.2 | 87.1 | 94.7 | 712 |
| 1909 | 76.5 | 272.0 | 134.9 | 106.9 | 102.1 | 0.0 | 0.0 | 2.5 | 50.5 | 47.8 | 46.7 | 131.8 | 972 |
| 1910 | 143.3 | 93.7 | 69.6 | 20.6 | 33.0 | 8.9 | 6.3 | 0.0 | 29.5 | 142.7 | 50.0 | 35.3 | 633 |
| 1911 | 72.4 | 61.0 | 214.1 | 62.0 | 50.3 | 20.3 | 44.4 | 12.2 | 6.3 | 73.7 | 145.5 | 12.2 | 774 |
| 1912 | 71.6 | 99.1 | 72.4 | 96.5 | 10.2 | 55.9 | 24.1 | 0.0 | 0.0 | 27.9 | 0.0 | 62.5 | 520 |
| 1913 | 72.6 | 197.4 | 168.9 | 43.2 | 0.0 | 8.1 | 16.5 | 16.8 | 71.1 | 30.5 | 52.1 | 8.9 | 686 |
| 1914 | 52.1 | 74.2 | 27.7 | 85.1 | 32.3 | 20.3 | 1.3 | 70.6 | 13.7 | 144.0 | 113.8 | 146.0 | 781 |
| 1915 | 113.0 | 148.8 | 25.9 | 27.4 | 61.7 | 0.0 | 17.0 | 0.0 | 6.3 | 30.0 | 91.4 | 58.9 | 580 |
| 1916 | 71.4 | 28.2 | 103.1 | 63.2 | 34.3 | 0.0 | 15.7 | 0.0 | 17.8 | 95.5 | 11.9 | 98.6 | 540 |
| 1917 | 110.0 | 129.3 | 110.0 | 45.7 | 18.3 | 15.7 | 27.2 | 34.3 | 54.9 | 15.5 | 50.8 | 102.1 | 714 |
| 1918 | 62.7 | 118.4 | 161.5 | 2.3 | 28.4 | 2.8 | 32.3 | 26.2 | 84.1 | 83.3 | 64.8 | 73.4 | 740 |
| 1919 | 89.9 | 48.3 | 89.2 | 42.7 | 2.8 | 1.8 | 18.5 | 10.2 | 27.4 | 11.2 | 143.8 | 23.9 | 510 |
| 1920 | 128.5 | 160.3 | 206.5 | 28.2 | 22.6 | 4.6 | 0.0 | 13.5 | 62.5 | 21.6 | 50.5 | 14.0 | 713 |
| 1921 | 57.9 | 134.1 | 152.9 | 96.3 | 17.5 | 8.6 | 0.0 | 0.0 | 35.1 | 46.7 | 71.6 | 143.5 | 764 |
| 1922 | 103.6 | 42.2 | 27.4 | 0.0 | 7.4 | 48.8 | 13.5 | 12.2 | 4.1 | 37.8 | 164.3 | 31.5 | 493 |
| 1923 | 195.8 | 152.1 | 55.1 | 73.2 | 87.9 | 23.9 | 30.5 | 4.6 | 3.8 | 29.5 | 49.8 | 9.1 | 715 |
| 1924 | 118.1 | 77.7 | 222.2 | 38.4 | 6.1 | 6.1 | 1.8 | 5.8 | 28.7 | 88.6 | 118.4 | 133.3 | 845 |
| 1925 | 93.2 | 119.6 | 232.9 | 141.0 | 115.6 | 0.0 | 0.0 | 7.6 | 16.3 | 18.8 | 71.9 | 56.4 | 873 |
| 1926 | 39.9 | 89.7 | 138.7 | 7.4 | 37.8 | 21.3 | 0.0 | 0.0 | 12.2 | 17.8 | 78.0 | 63.2 | 506 |
| 1927 | 63.0 | 40.6 | 240.3 | 5.1 | 5.6 | 0.0 | 14.0 | 5.6 | 2.0 | 82.5 | 44.4 | 120.9 | 624 |
| 1928 | 166.1 | 44.7 | 95.8 | 42.4 | 0.0 | 6.3 | 0.8 | 3.3 | 9.9 | 94.5 | 69.6 | 128.8 | 662 |
| 1929 | 93.0 | 61.0 | 125.2 | 5.3 | 27.4 | 45.7 | 36.1 | 17.5 | 154.9 | 54.6 | 58.7 | 168.4 | 848 |
| 1930 | 91.4 | 41.4 | 88.4 | 99.3 | 18.3 | 5.1 | 2.3 | 24.6 | 0.0 | 55.9 | 87.4 | 36.3 | 550 |
| 1931 | 120.4 | 80.8 | 138.2 | 129.3 | 0.0 | 0.0 | 67.6 | 0.0 | 0.0 | 97.8 | 120.4 | 70.4 | 825 |
| 1932 | 96.8 | 97.0 | 48.5 | 7.6 | 8.6 | 3.3 | 7.1 | 0.0 | 49.3 | 23.1 | 41.9 | 74.9 | 458 |
| 1933 | 140.7 | 67.6 | 49.8 | 50.3 | 10.2 | 8.6 | 0.0 | 2.0 | 0.3 | 15.7 | 154.7 | 164.6 | 665 |
| 1934 | 171.2 | 53.8 | 117.3 | 48.5 | 58.2 | 3.0 | 16.3 | 13.7 | 1.0 | 103.9 | 120.9 | 122.9 | 831 |
| 1935 | 51.8 | 76.7 | 120.4 | 83.8 | 82.5 | 4.1 | 5.8 | 56.1 | 2.8 | 52.8 | 64.3 | 84.6 | 686 |
| 1936 | 132.3 | 88.1 | 109.0 | 16.5 | 59.4 | 15.0 | 15.5 | 0.0 | 15.2 | 89.4 | 169.9 | 99.6 | 810 |
| 1937 | 274.6 | 214.6 | 107.7 | 3.3 | 29.2 | 5.6 | 11.2 | 0.0 | 2.3 | 12.7 | 19.3 | 99.6 | 780 |
| 1938 | 102.1 | 136.1 | 46.5 | 104.4 | 14.5 | 34.5 | 10.7 | 17.5 | 6.3 | 82.3 | 84.6 | 99.1 | 739 |
| 1939 | 190.2 | 134.1 | 24.6 | 33.8 | 45.2 | 6.3 | 34.8 | 65.5 | 16.0 | 140.2 | 76.5 | 49.5 | 817 |
| 1940 | 58.2 | 82.0 | 122.2 | 69.8 | 54.4 | 0.0 | 11.9 | 6.1 | 95.5 | 13.5 | 69.9 | 155.7 | 739 |
| 1941 | 85.6 | 132.6 | 31.8 | 50.0 | 12.7 | 2.8 | 31.5 | 9.1 | 18.8 | 108.7 | 30.0 | 54.6 | 568 |
| 1942 | 99.6 | 179.8 | 137.7 | 58.2 | 13.0 | 4.1 | 0.0 | 48.8 | 41.1 | 75.9 | 129.3 | 215.9 | 1003 |
| 1943 | 73.9 | 126.7 | 92.7 | 172.0 | 147.3 | 0.0 | 5.1 | 52.3 | 12.4 | 84.3 | 169.9 | 205.5 | 1142 |
| 1944 | 43.4 | 73.4 | 124.7 | 16.3 | 38.9 | 30.7 | 0.0 | 0.0 | 54.9 | 21.1 | 81.5 | 22.1 | 507 |
| 1945 | 100.8 | 54.6 | 121.2 | 4.3 | 53.5 | 0.8 | 0.0 | 0.0 | 0.3 | 14.0 | 45.0 | 87.9 | 482 |
| 1946 | 128.3 | 83.3 | 96.3 | 15.7 | 58.2 | 11.7 | 0.0 | 0.3 | 22.1 | 72.4 | 46.0 | 90.4 | 625 |
| 1947 | 67.6 | 112.0 | 16.8 | 64.3 | 42.7 | 6.6 | 11.4 | 5.3 | 72.4 | 75.2 | 95.3 | 162.6 | 732 |
| 1948 | 86.6 | 133.9 | 132.8 | 46.2 | 33.3 | 0.0 | 1.3 | 1.5 | 0.0 | 113.5 | 36.6 | 49.0 | 635 |
| 1949 | 53.6 | 47.0 | 82.6 | 8.6 | 41.9 | 6.9 | 13.5 | 0.0 | 13.0 | 47.8 | 157.2 | 87.6 | 560 |
| 1950 | 108.0 | 69.6 | 182.9 | 153.7 | 60.7 | 11.2 | 48.0 | 97.2 | 24.1 | 36.6 | 59.2 | 131.3 | 983 |
| 1951 | 82.4 | 89.0 | 129.7 | 90.4 | 19.3 | 30.2 | 10.7 | 10.4 | 49.1 | 124.9 | 10.2 | 13.4 | 660 |
| 1952 | 94.8 | 83.3 | 39.9 | 58.9 | 4.0 | 27.0 | 64.9 | 21.9 | 79.7 | 23.9 | 50.8 | 35.2 | 584 |
| 1953 | 47.7 | 191.9 | 71.9 | 95.9 | 22.4 | 0.0 | 0.0 | 6.9 | 18.8 | 79.4 | 69.0 | 81.5 | 685 |
| 1954 | 76.7 | 118.8 | 170.7 | 39.2 | 53.7 | 6.1 | 11.7 | 0.3 | 30.1 | 19.3 | 61.8 | 106.0 | 694 |
| 1955 | 212.2 | 228.4 | 61.5 | 95.2 | 33.2 | 16.5 | 12.2 | 1.9 | 0.0 | 92.5 | 111.5 | 100.1 | 965 |

continued...

PRECIPITATION DATA (MM) FOR MOHALE'S HOEK, LESOTHO (continued)

| YEAR | JAN | FEB | MARCH | APRIL | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1956 | 27.1 | 218.5 | 165.0 | 17.3 | 34.0 | 12.5 | 4.5 | 0.0 | 14.0 | 47.0 | 154.8 | 135.5 | 830 |
| 1957 | 107.5 | 115.9 | 111.8 | 42.5 | 14.5 | 0.0 | 44.0 | 67.5 | 162.0 | 186.0 | 115.0 | 59.7 | 1026 |
| 1958 | 241.0 | 87.0 | 59.0 | 45.1 | 82.0 | 0.0 | 0.0 | 0.0 | 23.7 | 57.3 | 152.2 | 168.0 | 915 |
| 1959 | 74.1 | 137.7 | 91.8 | 87.8 | 46.4 | 1.5 | 65.0 | 0.0 | 0.0 | 28.5 | 79.3 | 209.0 | 821 |
| 1960 | 160.6 | 145.5 | 97.4 | 82.0 | 26.8 | 27.7 | 16.7 | 52.6 | 33.2 | 74.2 | 90.6 | 44.1 | 851 |
| 1961 | 95.8 | 63.3 | 172.6 | 65.2 | 59.2 | 52.1 | 0.0 | 19.0 | 1.0 | 0.0 | 172.0 | 186.0 | 886 |
| 1962 | 84.0 | 196.0 | 74.5 | 59.0 | 5.5 | 0.0 | 3.5 | 0.0 | 3.0 | 16.5 | 130.2 | 74.5 | 647 |
| 1963 | 250.1 | 20.6 | 158.5 | 106.5 | 28.5 | 29.0 | 53.5 | 10.5 | 0.0 | 79.4 | 216.5 | 69.0 | 1022 |
| 1964 | 33.0 | 68.5 | 120.0 | 69.0 | 36.0 | 49.5 | 0.0 | 0.0 | 18.0 | 159.0 | 30.5 | 66.9 | 650 |
| 1965 | 57.8 | 42.7 | 49.5 | 64.0 | 2.0 | 29.5 | 6.8 | 10.0 | 12.5 | 10.0 | 72.3 | 50.5 | 408 |
| 1966 | 303.5 | 142.0 | 7.0 | 28.5 | 2.3 | 18.5 | 0.0 | 1.0 | 0.0 | 45.8 | 62.4 | 116.4 | 727 |
| 1967 | 244.5 | 61.3 | 102.0 | 148.5 | 80.8 | 9.1 | 15.3 | 21.7 | 6.0 | 78.4 | 45.3 | 13.1 | 826 |
| 1968 | 58.3 | 10.5 | 167.9 | 85.1 | 68.3 | 11.4 | 13.0 | 8.1 | 23.0 | 33.4 | 31.7 | 109.2 | 620 |
| 1969 | 76.1 | 158.1 | 116.7 | 88.9 | 30.1 | 3.2 | 0.8 | 23.5 | 12.5 | 95.7 | 28.6 | 64.3 | 699 |
| 1970 | 97.0 | 42.4 | 34.3 | 12.6 | 17.5 | 84.1 | 7.8 | 47.8 | 84.1 | 69.8 | 81.8 | 125.9 | 705 |
| 1971 | 58.4 | 128.4 | 71.0 | 56.0 | 0.0 | 0.0 | 21.6 | 11.1 | 3.0 | 37.6 | 38.1 | 56.8 | 482 |
| 1972 | 153.0 | 181.5 | 175.8 | 48.8 | 41.0 | 29.8 | 1.0 | 2.3 | 2.6 | 58.3 | 80.0 | 18.4 | 793 |
| 1973 | 34.9 | 112.5 | 54.2 | 70.1 | 35.7 | 1.3 | 7.3 | 52.6 | 39.5 | 13.5 | 79.0 | | |
| 1974 | 55.5 | 275.0 | 112.9 | 28.0 | 36.8 | 7.5 | 0.0 | 55.0 | 2.9 | 59.7 | 155.9 | 155.6 | 945 |
| 1975 | 82.9 | 34.0 | 89.6 | 79.7 | 18.0 | 31.0 | 10.0 | 9.8 | 69.8 | 29.4 | 97.5 | 193.8 | 746 |
| 1976 | 289.0 | | 196.5 | 59.0 | 16.0 | 7.5 | | | 85.0 | 165.2 | 17.4 | 105.4 | |
| 1977 | 124.3 | 43.2 | 69.3 | 30.1 | 18.9 | 3.5 | 0.0 | 6.8 | 68.8 | 119.6 | 42.2 | 107.6 | 634 |
| 1978 | 92.9 | 72.1 | 120.9 | 95.6 | 7.0 | 16.5 | 1.2 | 20.2 | 36.8 | 72.2 | 34.3 | 179.1 | 749 |
| 1979 | 46.0 | 124.5 | 46.5 | 32.2 | 23.4 | 8.5 | 47.5 | 57.5 | 54.0 | 128.0 | 41.5 | 15.5 | 625 |
| 1980 | | | 67.4 | 9.0 | 2.5 | 2.5 | 0.0 | 11.3 | 10.5 | 2.5 | 105.8 | 75.7 | |
| 1981 | 166.7 | 210.0 | 88.5 | 111.8 | 65.2 | 19.0 | 0.0 | 93.1 | | 20.6 | 79.4 | 61.7 | |
| 1982 | 43.4 | 77.5 | 95.5 | 167.7 | 0.0 | 37.0 | 20.0 | 0.0 | 14.8 | 139.9 | 40.4 | 76.0 | 712 |
| 1983 | 29.5 | 35.0 | 59.0 | 77.5 | 18.7 | 56.5 | 63.6 | | 20.0 | 46.0 | 124.3 | 128.5 | |
| 1984 | 92.8 | 26.9 | 100.5 | 32.5 | 35.5 | 12.8 | 0.0 | 77.0 | 0.5 | 28.0 | 75.8 | 29.1 | 511 |
| 1985 | 88.9 | 198.9 | 48.7 | 53.0 | 0.0 | 50.1 | 0.0 | 0.0 | 5.9 | 164.3 | 33.7 | 166.9 | 810 |
| 1986 | 115.2 | 60.0 | 56.1 | 3.0 | 0.0 | 24.5 | 0.0 | 35.0 | 30.7 | 121.7 | 102.3 | 25.6 | 574 |
| 1987 | 30.5 | 80.9 | 80.9 | 85.0 | 0.0 | 6.7 | 19.8 | 79.0 | 145.5 | 75.1 | 88.3 | | |
| NO. | 91 | 90 | 92 | 92 | 92 | 92 | 91 | 90 | 91 | 92 | 92 | 90 | 87 |
| MAX | 405.1 | 275.0 | 240.3 | 172.0 | 147.3 | 84.1 | 86.9 | 109.7 | 162.0 | 186.0 | 216.5 | 326.6 | 1142 |
| MIN | 21.6 | 10.5 | 7.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.9 | 408 |
| AVG | 107.6 | 104.6 | 103.1 | 59.0 | 34.1 | 15.7 | 13.8 | 19.5 | 30.9 | 63.4 | 79.0 | 95.5 | 715 |
| ST.DEV | 68.4 | 56.2 | 54.9 | 40.1 | 31.4 | 18.1 | 18.6 | 25.7 | 34.9 | 42.9 | 44.6 | 57.4 | 173 |

NOTE: Source of data - Ministry of Works and Communications, Hydrological Survey Department - Meteorological data to December 1970.
Data for 1970 till 1987 were obtained from Hydrological Survey Department.

# APPENDIX C

# GROUNDWATER LEVEL MONITORING NETWORK: BOREHOLE AND LOCATION DATA

APPENDIX C

# Meeling Observation Well

### Observation Well Borehole Data

**Location:** Village of Meeling (see detailed location map)
**Date drilled:** May 23, 1988
**Ground elevation:** 1685 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Borehole depth:** 37.0 m, below ground surface
**Depth water struck:** 25.2 m, below ground surface
**Completion method:** open hole
**Hole diameter:** 165 mm
**Length surface casing:** 4.0 m
**Casing diameter:** 165 mm
**Nearby borehole(s):** Meeling No. 6

### Lithology Observation Well Borehole

| | |
|---|---|
| 0 - 1.2 m | Top soil (clay) |
| 1.2 - 14.4 m | Brown sandstone |
| 14.4 - 17.0 m | Greenish brown shale |
| 17.0 - 34.2 m | Grey sandstone |
| 34.2 - 37.0 m | Grey shale |

### Recorder Data

**Type recorder:** Stevens, Type F, Model 68
**Date installed:** September 28, 1988
**Initial water level:** 17.01 m below top of casing
**Date initial water level:** September 28, 1988 @ 10:42 hrs.
**Float diameter:** 10.16 cm
**Total length beaded cable:** 28 m
**Gear ratio:** 1:10

### Rain Gauge Data

**Type of rain gauge:** Sierra-Misco, Model 2501
**Date installed:** September 30, 1988
**Height rim above ground:** 1.5 m
**Initial counter reading:** 0

# Meeling BH No. 6

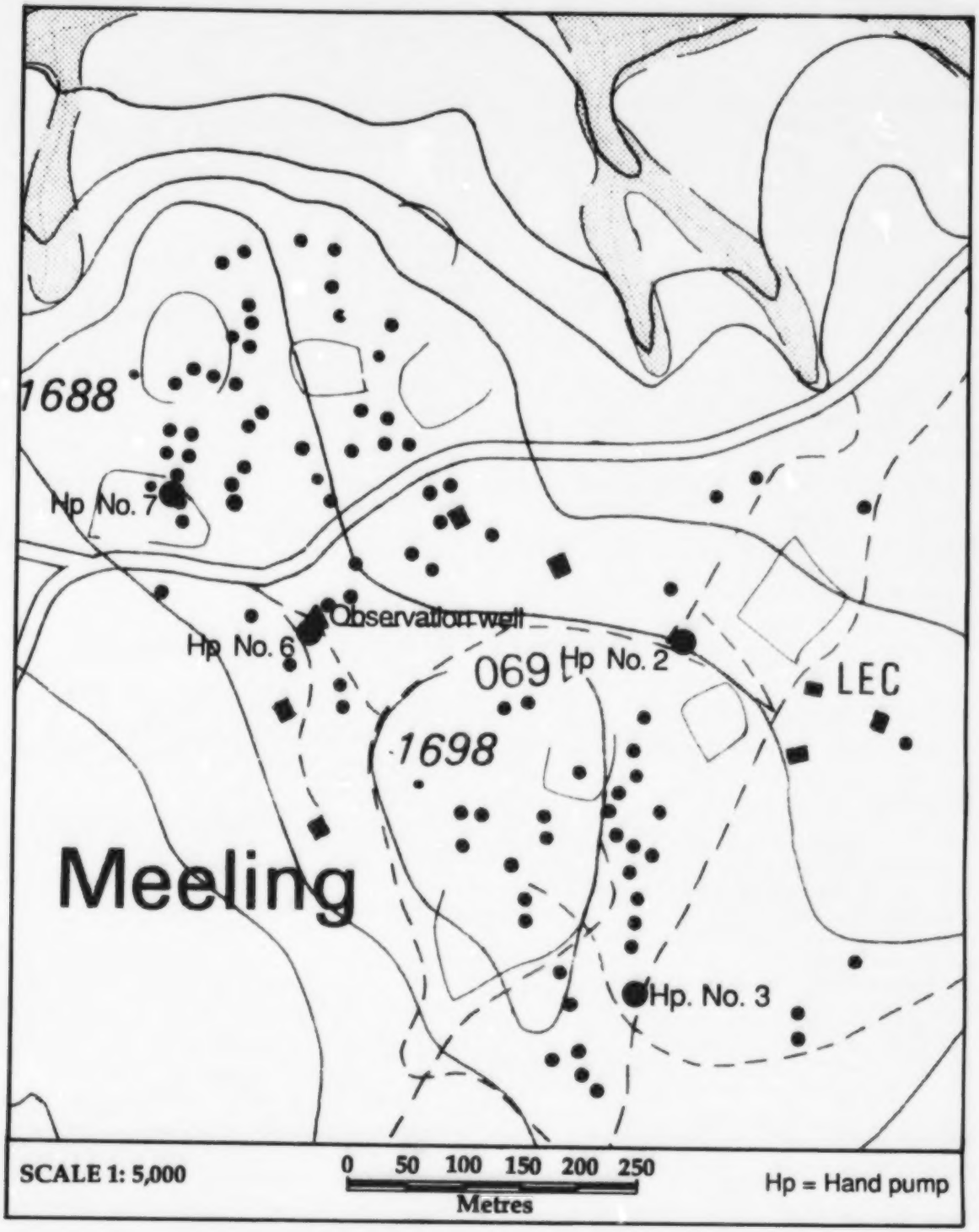
### Borehole Data Meeling BH No.6

**Location:** Village of Meeling (see detailed location map)
**Project:** MH 223
**Date drilled:** May 9, 1986
**Ground elevation:** to be surveyed in relative to top of casing of observation well
**Depth:** 53.4 m below ground surface
**Lithology:** data not obtained
**Distance from observation well:** 4 m
**"Static" water level:** 7.7 m below ground surface
**Date "static" water level measurement:** May 1986
**Type pump:** Mono handpump

**Initial flow meter reading:** 16.781 $m^3$
**Date flow meter reading:** September 28, 1988 @ 10:30 hrs

### Water Quality Data - Field Measurements

| Date | Water Temperature (C) | Ph | Electrical Conductivity (µS/CM @ 20 C) |
|---|---|---|---|
| 28/09/88 | 17.5 | 8.5 | 297 |
| 30/09/88 | 17.8 | 8.5 | 320 |
| 02/10/88 | 18.0 | 8.1 | 280 |
| 04/10/88 | 17.8 | 8.3 | 296 |
| 07/10/88 | 18.0 | 8.9 | 346 |




Meeling Observation Well Site

# Mokoroane Observation Well

### Observation Well Borehole Data

**Location:** Village of Mokoroane (see detailed location map)
**Date drilled:** May 21, 1988
**Ground elevation:** 1685 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Borehole depth:** 53.7 m below ground surface
**Depth water struck:** 9 - 10 m below ground surface
**Completion method:** open hole
**Hole diameter:** 165 mm
**Length surface casing:** 1.0 m
**Casing diameter:** 165 mm
**Neaby borehole(s):** Mokoroane BH No. 4, Mokoroane BH No. 1

### Lithology Observation Well Borehole

| | |
|---|---|
| 0 - 0.85 m | Top soil |
| 0.85 - 18.7 m | Sandstone |
| 18.7 - 19.5 m | Shale |
| 19.5 - 26.1 m | "Elliot mud" |
| 26.1 - 27.7 m | Shale/Sandstone |
| 27.7 - 34.9 m | Sandstone |
| 34.9 - 39.6 m | "Elliot mud" |
| 39.6 - 53.7 m | Shale |

### Recorder Data

**Type recorder:** Stevens, Type F, Model 68
**Date installed:** September 28, 1988
**Initial water level:** 7.12 m below top casing
**Date water level measurement:** September 28, 1988 @ 12:45 hrs
**Float diameter:** 10.16 cm
**Total length beaded cable:** 11 m
**Gear ratio:** 1:1

### Rain Gauge Data

**Type of rain gauge:** Sierra-Misco, Model 2501
**Date installed:** not yet installed
**Height rim above ground:**
**Initial counter reading:**

# Mokoroane BH No. 4

### Borehole Data Mokoroane BH No.4

**Location:** Village of Mokoroane (see detailed location map)
**Project:** MH 226
**Date drilled:** April 24, 1986
**Ground elevation:** to be surveyed in relative to the of casing of observation well
**Depth:** 40.4 m below ground surface
**Lithology:** data not obtained
**Distance from observation well:** 100 m
**"Static" water level:** 6.4 m
**Date "static" water level measurement:** April, 1986
**Type pump:** Mono handpump
**Initial flow meter reading:** 14.140 $m^3$
**Date flow meter reading:** September 28, 1988 @ 12:00

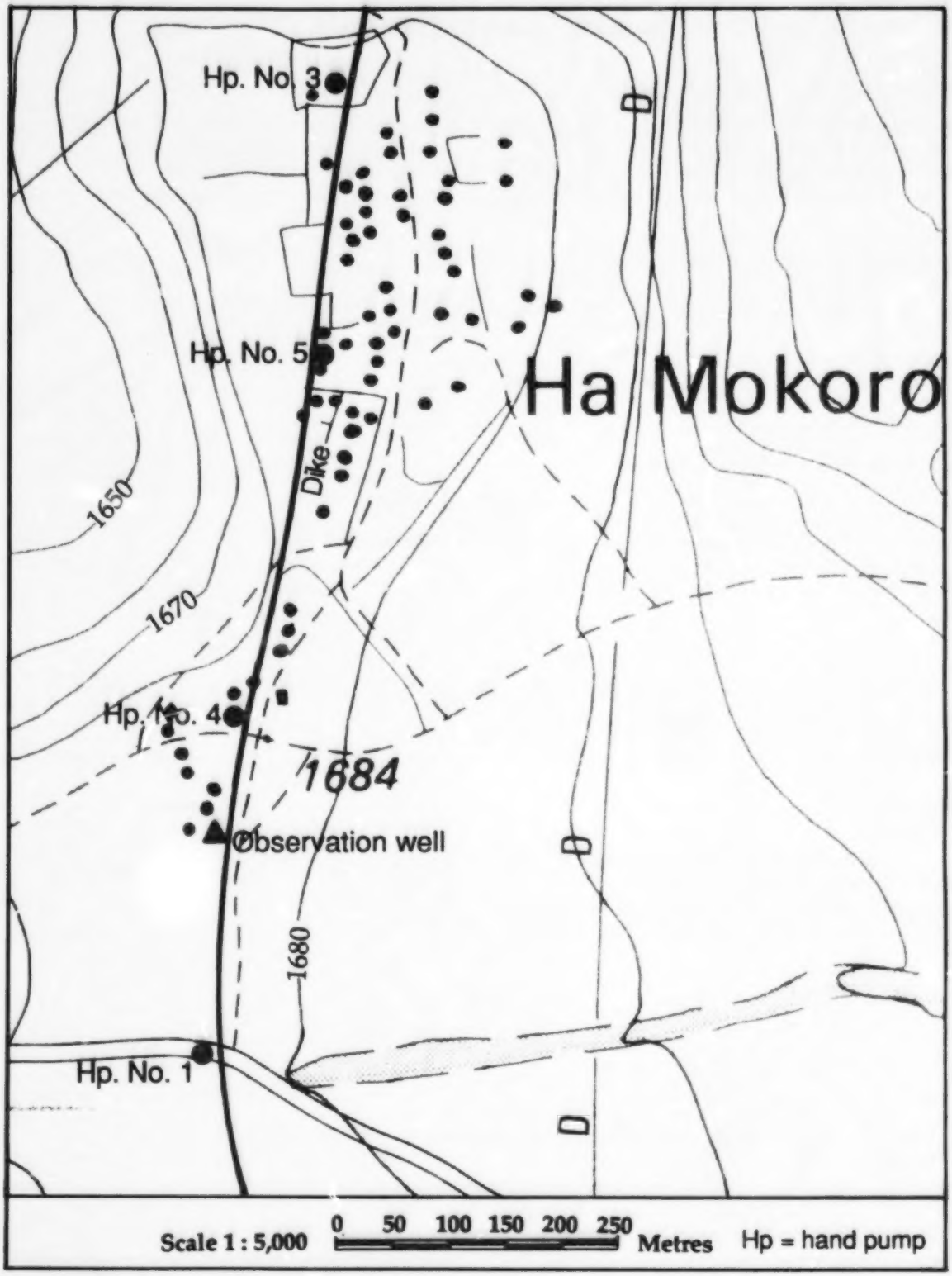
### Water Quality Data - Field Measurements

| Date | Water Temperature (C) | Ph | Electrical Conductivity (µS/CM @ 20 C) |
|---|---|---|---|
| 30/09/88 | 18 | 7.1 | 198 |
| 04/10/88 | 18 | 7.5 | 208 |
| 07/10/88 | 18 | 7.4 | 200 |

# Mokoroane BH No.1

### Borehole Data Mokoroane BH No. 1

**Location:** Village of Mokoroane (see detailed location map)
**Project:** MH 226
**Date drilled:** April 23, 1986
**Ground elevation:** to be surveyed in relative to top of casing of observation well
**Depth:** 30.0 m below ground surface
**Lithology:** data not obtained
**Distance from observation well:** 200 m
**"Static" water level:** 0.3 m below ground surface
**Date "static" water level measurement:** April, 1986
**Blow test yield:** 0.8 L/s
**Type pump:** wall caved in and pump taken off. New well drilled beside it but handpump not yet installed.
**Water level:** 0.21 m below top of casing
**Date water level measurement:** October 07, 1988




Mokoroane Observation Well Site

APPENDIX C

# Siloe Observation Well

## Observation Well Borehole Data

**Location:** Village of Siloe (see detailed location map)
**Date drilled:** May 25, 1986
**Ground elevation:** 1635 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Borehole depth:** 32.0 m below ground surface
**Depth water struck:** 12.0 and 25.0 m below ground surface
**Completion method:** open hole
**Hole diameter:** 165 mm
**Length surface casing:** 8.4 m
**Casing diameter:** 165 mm
**Nearby borehole(s):** Siloe production well
**Blow test yield:** appr. 2 L/s

## Lithology Observation Well Borehole

| | |
|---|---|
| 0- 6.7 m | Clay (wet) |
| 6.7-10.4 m | Brown/greenish sandstone |
| 10.4-11.0 m | Blue sandstone |
| 11.0-28.0 m | Brown sandstone |
| 28.0-32.0 m | Red mudstone |

## Recorder Data

**Type recorder:** Stevens, Type F, Model 68
**Date installed:** September 26, 1988
**Initial water level:** FLOWING
**Date intitial water level:** September 26, 1988 @ 12:15
**Total length beaded cable:** 9 m
**Gear ratio:** 1:20

## Water Quality Data

| Date | Water Temperature (C) | Ph | Electrical Conductivity (µS/CM @ 20 C) |
|---|---|---|---|
| 28/09/88 | 17.5 | 7.4 | 338 |
| 30/09/88 | 17.5 | 7.6 | 338 |
| 07/10/88 | 18.0 | 7.9 | 365 |

**Measuring point:** discharge outlet from flowing observation well

## Rain Gauge Data

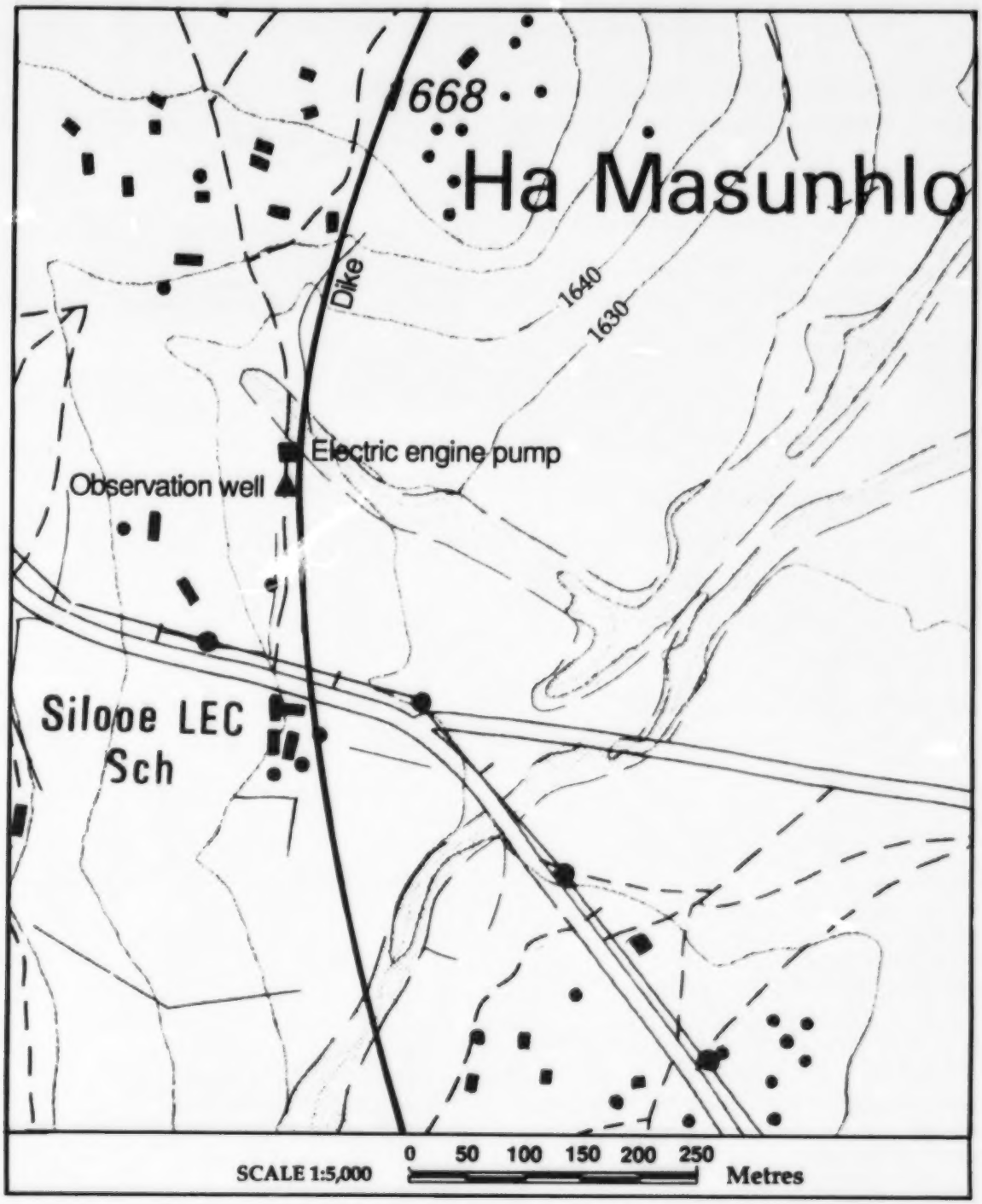
**Type of rain gauge:** Sierra-Misco, Model 2501
**Date installed:** September 30, 1988
**Height rim above ground:** 1.5 m
**Initial counter reading:** 0

# Siloe Production Well

## Borehole Data Siloe Production Well

**Location:** Village of Siloe
**Project:** MH-71
**Date drilled:** 1977
**Ground elevation:** to be surveyed in relative to top of casing of observation well
**Depth:** 44.0 m below ground surface
**Distance from observation well:** 8.3 m

**Initial water level:** 8.7 m above ground level
**Date intitial water level:** 1977
**Type pump:** electrical driven Mono ES 15 DH pump
**Pumping rate:** 1.0 - 1.5 L/s
**Initial flow meter reading:** 0
**Date flow meter reading:** October 07, 1988




Siloe Observation Well Site

APPENDIX C

# Brakfontein Observation Well

### Observation Well Borehole Data

**Location:** Village of Brakfontein (see detailed location map)
**Date drilled:** June 17, 1988
**Ground elevation:** 1625 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Borehole depth:** 67.0 m below ground surface
**Depth water struck:** 39.0 and 57.0 m below ground surface
**Completion method:** open hole
**Hole diameter:** 165 mm
**Length surface casing:** 4.0 m
**Casing diameter:** 165 mm
**Nearby borehole(s):** Brakfontein No. 1 and Brakfontein No. 4

### Lithology Observation Well Borehole

| | |
|---|---|
| 0- 1 m | Fine yellow sandstone |
| 1- 4.4 m | Red shale |
| 4.4- 6.2 m | Fine yellow standstone |
| 6.2-14.0 m | Green shale |
| 14.0-19.6 m | Blue sandstone |
| 19.6-53.4 m | Red shale |
| 53.4-67.0 m | Blue sandstone |

### Recorder Data

**Type recorder:** Stevens, Type F, Model 68
**Date installed:** September 27, 1988
**Initial water level:** 18.953 m below top casing
**Date initial water level:** September 27, 1988 @ 12:15
**Float diameter:** 10.16 cm
**Total length beaded cable:** 30 m
**Gear ratio:** 1:1 (to be changed to 1:5)

### Rain Gauge Data

**Type of rain gauge:** Sierra-Misco, Model 2501
**Date installed:** October 01, 1988
**Height rim above ground:** 1.5 m
**Initial counter reading:** 100

# Brakfontein No. 1

### Borehole Data Brakfontein No. 1

**Location:** Village of Brakfontein (see detailed location map)
**Project:** not known
**Date drilled:** not recorded
**Ground elevation:** to be surveyed in relative to top of casing of observation well
**Depth:** not known
**Lithology:** data not obtained
**Distance from observation well:** appr. 125 m
**"Static" water level:** not recorded
**Type pump:** Moyno pump
**Initial flow meter reading:** 3.212 $m^3$
**Date flow meter reading:** October 01, 1988 @ 09:00 hrs.

### Water Quality Data - Field Measurements

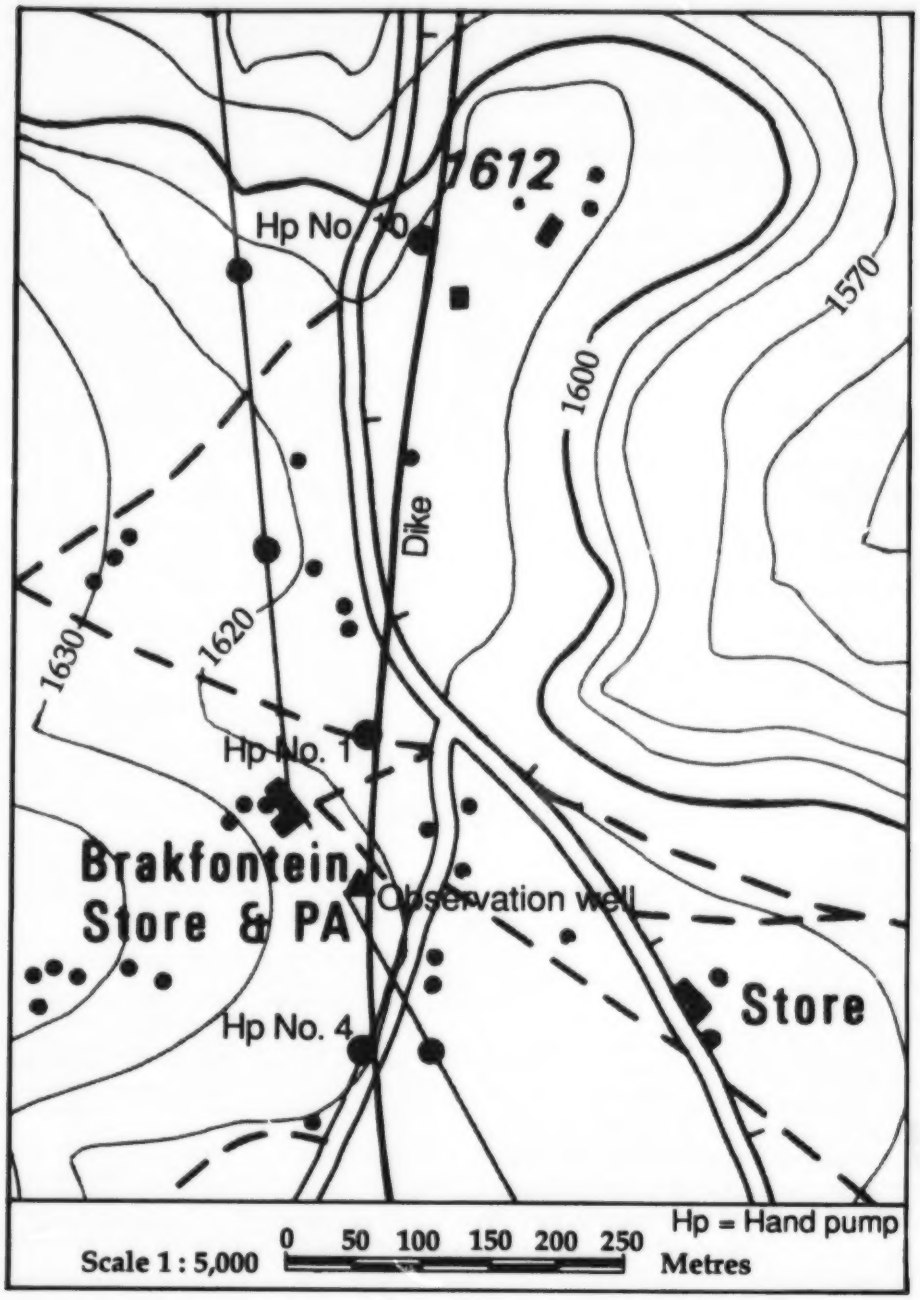
| Date | Water Temperature (C) | Ph | Electrical Conductivity (µS/CM @ 20 C) |
|---|---|---|---|
| 04/10/88 | 18 | 7.8 | 740 |
| 05/10/88 | 18 | 7.3 | 720 |
| 07/10/88 | 18 | 7.8 | 747 |

# Brakfontein No. 4

**Location:** Village of Brakfontein (see detailed location map)
**Project:** not known
**Date drilled:** not recorded
**Ground elevation:** to be surveyed in relative to top of casing of observation well
**Depth:** not recorded
**Lithology:** lithological data not obtained
**Distance from observation well:** 130 m
**"Static" water level:** not recorded
**Date "static" water level:** not recorded
**Type pump:** Moyno handpump
**Initial flow meter reading:** flow meter not yet installed

### Water Quality Data - Field Measurements

| Date | Water Temperature (C) | Ph | Electrical Conductivity (µS/CM @ 20 C) |
|---|---|---|---|
| 04/10/88 | 17.5 | 7.8 | 460 |
| 05/10/88 | 17.8 | 7.6 | 490 |
| 07/10/88 | 18.0 | 7.7 | 485 |




Brakfontein Observation Well Site

# Setotoma Observation Well

### Observation Well Borehole Data

**Location:** Village of Setotoma (see detailed location map)
**Date drilled:** June 6, 1988
**Ground elevation:** 1525 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Borehole depth:** 87.0 m below ground surface
**Depth water struck:** 45 and 82 m below ground surface
**Completion method:** open hole
**Hole diameter:** 165 mm
**Length surface casing:** 4.0 m
**Casing diameter:** 165 mm
**Blow yield:** appr. 0.3 L/s @ 45 m and 3.3 L/s @ 82 m
**Nearby borehole(s):** Setotoma production well

### Lithology Observation Well Borehole

| | |
|---|---|
| 0-16.4 m | Light brown sandstone |
| 16.4-17.0 m | Red brown sandstone |
| 17.0-18.4 m | Brown sandstone |
| 18.4-52.0 m | Dolerite |
| 52.0-87.0 m | Grey sandstone |

### Recorder Data

**Type recorder:** Stevens, Type F, Model 68
**Date installed:** September 27, 1988
**Initial water level:** 36.69 m below top casing
**Date initial water level:** September 27, 1988 @ 13:45 hrs.
**Float diameter:** 10.16 cm
**Total length beaded cable:** 62 m
**Gear ratio:** 1:20

### Rain Gauge Data

**Type of rain gauge:** Sierra-Misco, Model 2501
**Date installed:** October 01, 1988
**Height rim above ground:** 1.5 m
**Initial counter reading:** 0

# Setotoma Production Well

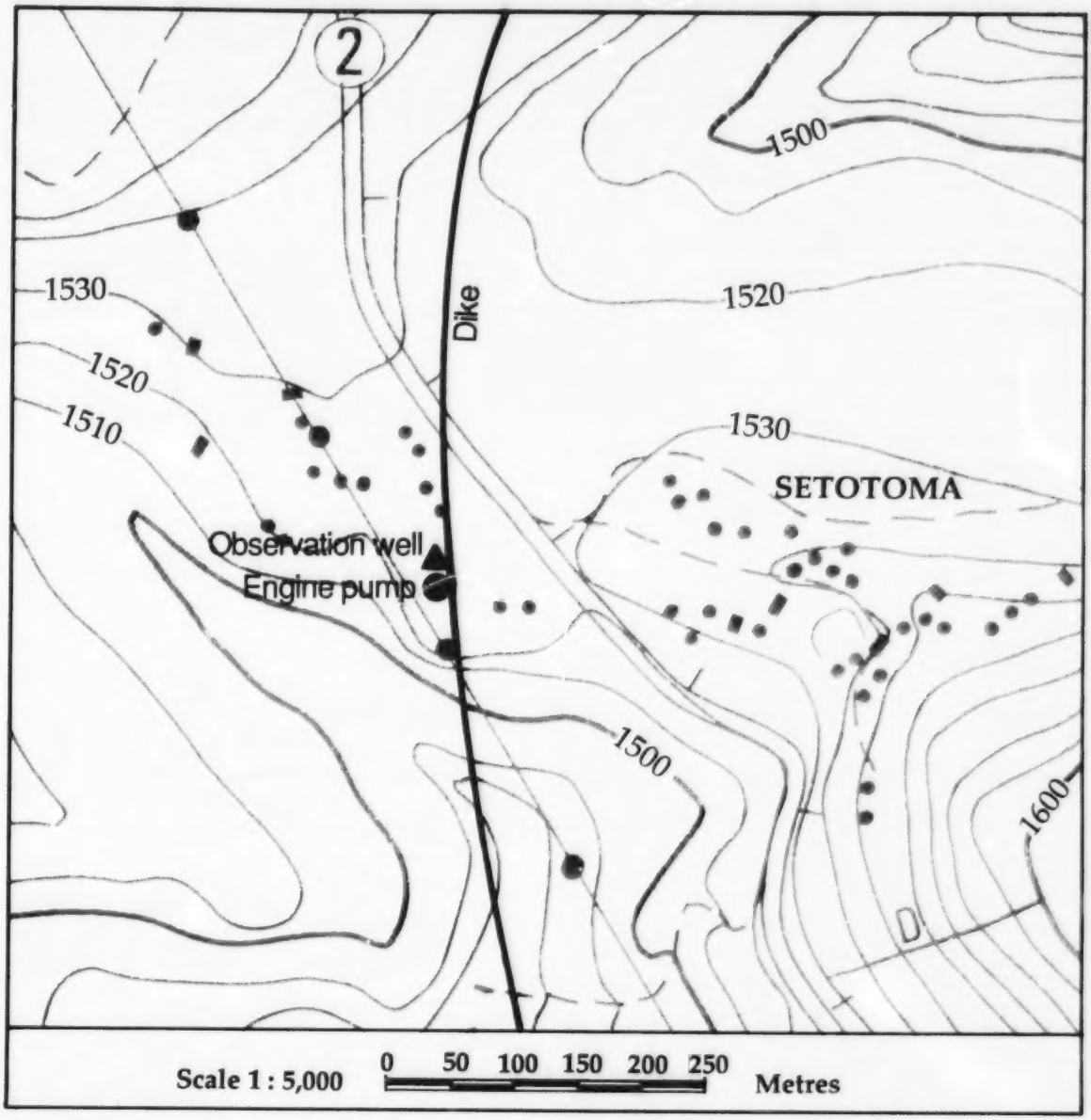
### Borehole Data Setotoma Production Well

**Location:** Village of Setotoma (see detailed location map)
**Project:** MH110
**Date drilled:** 1985
**Ground elevation:** to be surveyed in relative to top of casing of observation well
**Depth:** 81 m below ground surface
**Lithology:** lithological data not obtained
**Distance from observation well:** 5.5 m
**"Static" water level:** 39.5 m below ground surface
**Date "static" water level measurement:** November 21, 1985
**Type pump:** diesel engine pump
**Initial flow meter reading:** 0.67 $m^3$
**Date flow meter reading:** September 27, 1988 @ 14:00 hrs.

### Water Level Measurements

**Date:** September 29, 1988
**Pump started:** 10:40 hrs.

| Time | Water level in production well (in metres below pump plate) |
|---|---|
| 10:40 | 35.76 |
| 11:40 | 38.03 |
| 14:58 | 40.258 |
| 15:58 | 40.75 |
| 16:00 | pump shut off |




Setotoma Observation Well Site

# Holy Cross Observation Well

### Observation Well Borehole Data

**Location:** Village of Holy Cross (Ha Theka) (see detailed location map)
**Date drilled:** June 23, 1988
**Ground elevation:** 1540 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Borehole depth:** 67.0 m below ground surface
**Depth water struck:** 39 m below ground surface
**Completion method:** open hole
**Hole diameter:** 165 mm
**Length surface casing:** 4.0 m
**Casing diameter:** 165 mm
**Nearby borehole(s):** Ha Theka (Holy Cross) No.1 and Holy Cross submersible borehole

### Lithology Observation Well Borehole

| | | | |
|---|---|---|---|
| 0 | - | 1 m | Grey top soil |
| 1 | - | 2 m | Grey shale |
| 2 | - | 3 m | Red shale |
| 3 | - | 7 m | Green shale |
| 7 | - | 9 m | Brown sandstone |
| 9 | - | 21 m | Fine grey sandstone |
| 21 | - | 55 m | Grey sandstone |
| 55 | - | 67 m | Red shale |

### Recorder Data

**Type recorder:** Stevens, Type F, Model 68
**Date installed:** September 27, 1988
**Initial water level:** 23.74 m below top casing
**Date initial water level measurement:** September 27, 1988 @ 15:30 hrs
**Float diameter:** 10.16 cm
**Total length beaded cable:** 40 m
**Gear ratio:** 1:20

### Rain Gauge Data

**Type of rain gauge:** Sierra-Misco, Model 2501
**Date installed:** October 01, 1988
**Height rim above ground:** 1.5 m
**Initial counter reading:** 210

# Ha Theko (Holy Cross) No. 1

### Borehole Data Ha Theko (holy Cross) No.1

**Location:** Village of Ha Theko (see detailed location map)
**Project:** not recorded
**Date drilled:** not recorded
**Ground elevation:** to be surveyed in relative to top of casing of observation well
**Depth:** 55 m below ground surface
**Lithology:** lithological data not obtained
**Distance from observation well:** 31 m
**"Static" water level:** not recorded
**Date "static" water level measurement:** not recorded
**Type pump:** Moyno handpump
**Initial flow meter reading:** 4.547 $m^3$
**date flow meter reading:** September 29, 1988 @ 13:06

### Water Quality Data - Field Measurements

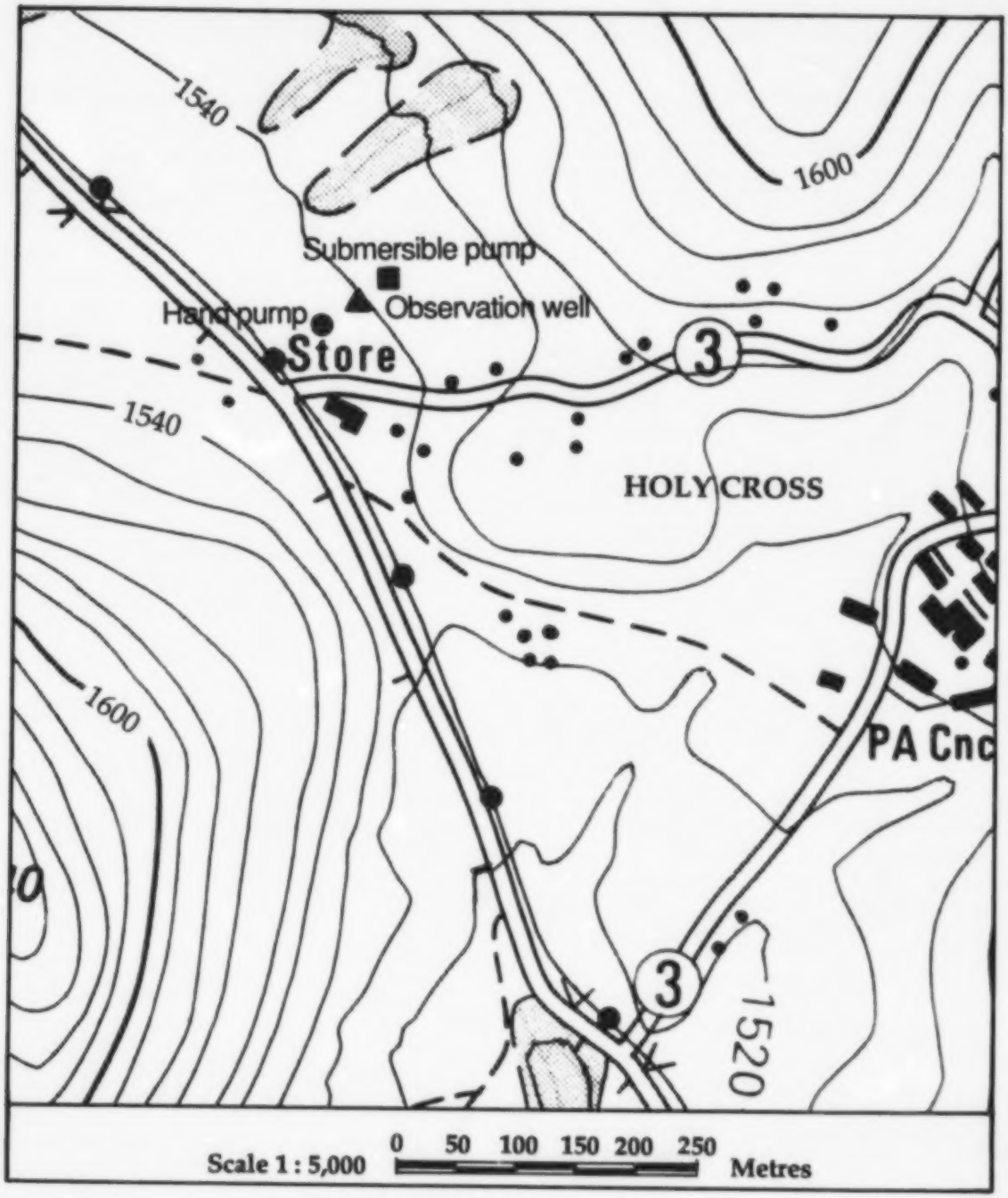
| Date | Water Temperature (C) | Ph | Electrical Conductivity (µS/CM @ 20 C) |
|---|---|---|---|
| 29/09/88 | 18.3 | 7.3 | 480 |
| 03/10/88 | 18.0 | 7.8 | 520 |
| 07/10/88 | 18.0 | 7.9 | 490 |

# Holy Cross Submersible Borehole

### Borehole Data Holy Cross Submersible Borehole

**Location:** Village of Ha Theko (see detailed location map)
**Project:** unknown
**Date drilled:** unknown
**Ground elevation:** to be surveyed in relative to top of casing of observation well
**Depth:** unknown
**Lithology:** data not obtained
**Distance from observation well:** 26 m
**"Static" water level:** not reported
**Date "static" water level measurement:** not reported
**Type pump:** submersible
**Intital flow meter reading:** 0 $m^3$
**Date flow meter reading:** September 27, 1988 @ 12:45

Continued on page 48...




Holy Cross Observation Well Site

## APPENDIX C

### Water Level Data

**Date:** October 03, 1988
**Time pump started:** 11:00 hrs

| Time | Water Level | |
|---|---|---|
| | **Submersible Well** (in m below pump plate) | **Observation Well** (in m below top casing) |
| 10:59 | 23.965 | |
| 11:15 | 27.33 | |
| 11:23 | | 24.42 |
| 11:30 | 28.12 | |
| 11:45 | 28.75 | |
| 11:47 | | 24.38 |
| 11:58 | | 24.36 |
| 12:00 | 29.04 | |
| 12:15 | 29.30 | |
| 12:20 | | 24.33 |
| 12:30 | 29.37 | |
| 12:45 | 29.76 | |
| 12:55 | 29.80 | |
| 12:55 | Submersible pump shut off | |
| 13:00 | 28.19 | |
| 13:04 | | 24.26 |
| 13:10 | 27.56 | |
| 13:15 | 27.35 | |
| 13:20 | 27.15 | |
| 13:25 | 26.96 | |
| 13:30 | 26.78 | |
| 13:45 | 26.23 | |
| 14:00 | 25.91 | |
| 14:15 | 25.59 | |
| 14:30 | 25.37 | |
| 15:03 | | 23.98 |
| 15:10 | 24.97 | |
| 16:15 | 24.65 | |

# DATA FOR WELLS MEASURED MONTHLY

## Kobo Tsoeu (Ha Malebanye) No. 1

**Location:** see Map No. 1
**Project:** not reported
**Date drilled:** not reported
**Ground elevation:** 1450 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 52 m below ground surface
**"Static" water level:** 32 m below ground surface
**Date "static" water level measurement:** not reported
**Blow yield:** 0.6 L/s

## Mesitsaneng No. 4

**Location:** see Map No. 1
**Project:** not reported
**Date drilled:** 1985
**Ground elevation:** 1550 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 45.7 m below ground surface
**"Static" water level:** 23.4 m below ground surface
**Date "static" water level measurement:** December 21, 1985
**Bail test data:** December 21, 1985

| Time | Bails removed | Water level |
|---|---|---|
| 07:15 | 10 (300 L) | 30.5 m |
| 07:25 | 10 (300 L) | 36.6 m |
| 07:42 | 7 (210 L) | 41.5 m |
| | | RECOVERY |
| 07:55 | | 41.5 m |
| 08:10 | | 30.5 m |
| 08:25 | | 26.0 m |
| 08:40 | | 23.0 m |

## Mesitsaneng No. 20

**Location:** see map No. 1
**Project:** not repoted
**Date drilled:** February 19, 1986
**Ground elevation:** 1525 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 52.0 m below ground surface
**"Static" water level:** 32.0 m below ground surface
**Date "static" water level measurement:** February 19, 1986
**Blow yield:** 0.7 L/s

## Ha Sekoati No. 6

**Location:** see Map No. 1
**Project:** not reported
**Date drilled:** 1985
**Ground elevation:** 1625 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 57.4 m below ground surface
**"Static" water level:** 13.4 m below ground surface
**Date "static" water level measurement:** November 11, 1985
**Bail test data:** November 11, 1985

| Time | Bails removed | Water level |
|---|---|---|
| 16:00 | 10 (300 L) | 23.5 m |
| 16:15 | 10 (300 L) | 30.2 m |
| 16:30 | 10 (300 L) | 32.9 m |
| 16:45 | 10 (300 L) | 32 9 m |
| 17:05 | 10 (300 L) | 32.9 m |
| | | RECOVERY |
| 17:20 | | 32.9 m |
| 17:25 | | 24.2 m |
| 17:40 | | 17.0 m |
| 18:15 | | 13.9 m |

## Ha Theko No. 2

**Location:** see Map No. 1
**Project:** not reported
**Date drilled:** June 22, 1988
**Ground elevation:** 1545 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 57 m below ground surface
**Depth water struck:** 17 and 42 m below ground surface
**"Static" water level:** not reported
**Date "static" water level measurement:** not reported
**Blow yield:** 3.3 L/s
**Lithology:** 0- 14 mBrown sandstone
14- 17 mGreen shale
17- 24 mBrown sandstone
24- 57 mGrey sandstone

## Rabele No. 3

**Location:** see map No. 1
**Project:** not reported
**Date drilled:** August 20, 1988
**Ground elevation:** 1555 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 49 m below ground surface
**Depth water struck:** 26 and 34 m below ground surface
**"Static" water level:** not reported
**Date "static" water level measurement:** not reported Blow yield: 0.8 L/s
**Lithology:** 0- 18 mGrey sandstone
18- 22 mFine brown sandstone
22- 49 mFine grey sandstone

APPENDIX C

## Ha Khitsane (Ha Mokhethi) No. 7

**Location:** see map No. 1
**Project:** not reported
**Date drilled:** not reported
**Ground elevation:** 1540 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 31 m below ground surface
**Depth water struck:** not reported
**"Static" water level:** 14.5 m below ground surface
**Date "static" water level measurement:** not reported
**Blow yield:** 0.6 L/s

## Ha Panta No. 3

**Location:** see Map No. 1
**Project:** not reported
**Date drilled:** 1986
**Ground elevation:** 1468 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 72.4 m below ground surface
**Depth water struck:** not reported
**"Static" water level:** 3.4 m below ground surface
**Date "static" water level measurement:** June 26, 1986
**Bail test data:** June 26, 1986

| Time | Bails Removed | Water level |
|---|---|---|
| 10:55 | 10 (300 L) | 16.0 m |
| 11:05 | 10 (300 L) | 27.6 m |
| 11:15 | 10 (300 L) | 40.0 m |
| 11:30 | 10 (300 L) | 50.8 m |
| 11:40 | 10 (300 L) | 59.4 m |
| 11:55 | 10 (300 L) | 70.7 m |
| | | RECOVERY |
| 12:20 | | 70.7 m |
| 12:35 | | 57.0 m |
| 12:55 | | 42.7 m |
| 15:00 | | 14.2 m |
| 17:00 | | 7.0 m |

## Maseroue No. 1

**Location:** see Map No. 1
**Project:** MH244
**Date drilled:** May, 1986
**Ground elevation:** 1610 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 48.0 m below ground surface
**Depth water struck:** not reported
**"Static" water level:** 4.0 m below ground surface
**Date "static" water level measurement:** May, 1986
**Blow yield:** 0.6 L/s

## Tsoloane No. 1

**Location:** see map No. 1
**Project:** not reported
**Date drilled:** 1987
**Ground elevation:** 1565 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 48.0 m below ground surface
**Depth water struck:** not reported
**"Static" water level:** 18.3 m below ground surface
**Date "static" water level measurement:** January 17, 1987
**Bail test data:** January 17, 1987

| Time | Bails removed | Water level |
|---|---|---|
| 16:20 | 10 (300 L) | 20.0 m |
| 16:33 | 10 (300 L) | 21.2 m |
| 16:54 | 10 (300 L) | 21.9 m |
| 17:10 | 10 (300 L) | 22.0 m |
| 17:24 | 10 (300 L) | 22.1 m |
| 17:39 | 10 (300 L) | 22.1 m |
| 17:55 | 10 (300 L) | 22.1 m |
| | | RECOVERY |
| 18:10 | | 22.1 m |
| 18:25 | | 18.6 m |

## Meriting No. 2

**Location:** see map No. 1
**Project:** not reported
**Date drilled:** 1984
**Ground elevation:** 1530 m above sea level
**Source for ground elevation:** 1:20,000 topographical map
**Total depth:** 42.8 m below ground surface
**Depth water struck:** not reported
**"Static" water level:** 6.8 m below ground surface
**Date "static" water level measurement:** August 7, 1984
**Bail test data:** August 7, 1984 (Recovery Data only.)

| Time | Bails Removed | Water level |
|---|---|---|
| 08:40 - 8:58 hrs. | 21 (630 L) | |
| | | RECOVERY |
| 08.58 | | 40.8 m |
| 09.15 | | 30.7 m |
| 10:00 | | 11.8 m |
| 11:00 | | 7.3 m |
| 12:00 | | 7.1 m |